TECHNICAL SERVICE CENTER
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ARROWROCK RESERVOIR SEDIMENT QUANTIFICATION AND TRANSPORT STUDY REPORT

Prepared by

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EXECUTIVE SUMMARY

Arrowrock Dam was constructed by the Bureau of Reclamation in 1915 to provide irrigation and flood control for the Boise Project, Idaho (figure 1). The dam is located in Elmore County about 15 miles east of Boise, Idaho and about 4 miles below the confluence of the North and South Forks of the Boise River (figure 2). Lucky Peak Dam, a zoned earthfill dam built by the Corps of Engineers in 1955, is located approximately 12 miles downstream from Arrowrock Dam. Flows from Arrowrock Dam are released directly into Lucky Peak Reservoir, which forms the tailwater for Arrowrock Dam. The Arrowrock Dam Outlet Works Rehabilitation Project is proposing to replace the 10 lower level ensign valves with clamshell gates located on the downstream side of Arrowrock Dam. After the clamshell gates are installed, the ten, upper-level ensign valves and the five sluice gates would be abandoned. The Sedimentation and River Hydraulics Group of the Technical Service Center was requested to study sediment impacts for Alternative A of the Arrowrock Dam Outlet Works Rehabilitation Project. Alternative A requires Arrowrock and Lucky Peak Reservoirs to be partially drawn down during Year 3 of the construction (November 1 to February 28). If a 5-year or greater flood event occurs during this period, the sluice gates will be opened to maintain the drawdown lake elevation in Arrowrock Reservoir. In 1997, a reservoir survey showed that 20 feet of sediment has accumulated above the outlets of the sluice gates. The purpose of the sedimentation study is to estimate the quantity of sediment that would be flushed through Arrowrock Dam if the sluice gates are opened, and what portion of the flushed sediment will be trapped in Lucky Peak Reservoir.

On average, since the last major sediment flushing in 1987, Arrowrock Reservoir is lowered to elevation 3,043[1] each year and Lucky Peak Reservoir is lowered to elevation 2,930. During the first two years of the proposed valve replacement on Arrowrock Dam, Arrowrock Reservoir will be held at elevation 3,110 (68 feet above the average annual minimum lake elevation). Lucky Peak Reservoir will be held at elevation 3,000 (80 feet above the average annual minimum lake elevation). During the third and final year of the proposed valve replacement, Arrowrock Reservoir will be lowered to elevation 3,027 (16 feet below the average annual minimum lake elevation). Full drawdown to the Arrowrock Dam sluice gates is 76 feet below the average annual minimum. Lucky Peak Reservoir will be held at elevation 3,000 from September 1 to October 31, and then lowered to elevation 2,962, below the outlet of the sluice gates on Arrowrock Dam, between November 1 and February 28 (32 feet above the above the average annual minimum lake elevation).

Sediment flushing events are characterized by large changes in the rate of channel erosion and the suspended-solids concentration in the flow exiting the dam. The variations in sediment released primarily depends on the availability and erodibility of fine sediment during the flushing event. During the partial drawdown of either Arrowrock or Lucky Peak Reservoir for the proposed valve replacement, minor reworking of existing sediment along the reservoir bottoms will occur. If the sluice gates are never operated during the valve replacement project, (assuming the reservoir is not completely drawn down) the impact of Arrowrock Reservoir sediment on turbidity is negligible.

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[1]All elevations are presented in feet.

If the sluice gates are opened during Year 3 to pass a flood, short-term, high sediment concentrations will be released from each gate causing a portion of the sediment deposited upstream of Arrowrock Dam to be flushed into Lucky Peak Reservoir. Based on the size of the sediment measured upstream of Arrowrock Dam and partially drawn down lake elevation during Year 3, it is estimated that each sluice gate will cause approximately two acre-feet of silt sized sediment to be flushed into Lucky Peak Reservoir if the sluice gates are opened to pass a 5- to 10-year storm. If all five sluice gates are operated, a total of 8 to10.5 acre-ft of silt sized sediment is estimated to be flushed out of Arrowrock Reservoir. In addition, it is estimated that 80-95% of any sediment carried by a storm to Arrowrock Reservoir may also be passed through the reservoir and sluice gates to Lucky Peak Reservoir.

If for any reason during the valve replacement the reservoir were emptied, the amount of sediment flushed through the reservoir will be significantly greater than if the gates are used only to maintain the partial drawdown level. At a full drawdown of Arrowrock Reservoir to elevation 2,967, the sediment flushed into Lucky Peak Reservoir would increase by an order of magnitude (a factor of 10 to possibly a factor of 100) (Morris and Fan, 1998). The majority of sediment flushed would be in the final drawdown stages. Volumes of sediment flushed, assuming all five sluice gates are operated during the entire drawdown, are estimated to reach 520 to 1250 acre-ft. These estimates depend on the upstream extent of channel scouring that would actually occur.

Because Arrowrock and Lucky Peak Reservoirs are located in series, if the sluice gates are used to pass a flood during Year 3, a portion of the sediments released will accumulate in Lucky Peak Reservoir. During the construction period (from September 1 to October 31 when Lucky Peak Reservoir would be held at lake elevation 3,000), it is estimated that at least **b** of the sediment flushed from Arrowrock Reservoir will be trapped in Lucky Peak Reservoir. When Lucky Peak is drawn down to lake elevation 2,962 (during November 1 to February28), at least ½ of the sediment flushed is estimated to become trapped in Lucky Peak Reservoir. The remaining flushed sediment will be transported farther downstream and has the potential to be passed through Lucky Peak Dam after several storm events. This depends on the magnitude and duration of the storm events, and the operation of the outlet works at Arrowrock and Lucky Peak Dams. When Lucky Peak is drawn down in Year 3 to elevation 2,962, the water travel time during a 5- to 10-year storm event is approximately 7 to 10 days. It is unlikely that the sluice gates on Arrowrock Dam would be opened long enough for the majority of flushed sediment to reach Lucky Peak Dam (unless the sluice gates were operated for longer than a 1 week period). A more likely scenario is the sediment will gradually be reworked throughout Lucky Peak Reservoir, and eventually reach the dam over time.

Sediment flushing events are very unstable and difficult to measure due to the rapidly changing channel geometry, inflow, lake elevation, and outlet configurations. However, it may be beneficial to collect some data for future reference if the sluice gates are operated for a long enough duration during the valve replacement project. Possible data collection could involve monitoring Arrowrock and Lucky Peak Reservoirs for evidence of a density current through temperature, dissolved oxygen, or suspended sediment measurements, recording duration of sluice gate operation and lake elevation, and visual observations of flushing. Possibly the most beneficial piece of information would be to survey Arrowrock and Lucky Peak Reservoirs prior to the proposed valve replacement and just after a possible flushing event. This would verify the volume of sediment flushed out of Arrowrock Reservoir, and the volume trapped in Lucky Peak Reservoir.

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INTRODUCTION

Arrowrock Dam was constructed by the Bureau of Reclamation in 1915 to provide irrigation and flood control for the Boise Project, Idaho (figure 1). The dam is located in Elmore County about 15 miles east of Boise, Idaho and about 4 miles below the confluence of the North and South Forks of the Boise River (figure 2). Arrowrock Dam is the second dam in a series of four dams in the Boise River Project. Anderson Dam is located approximately 40 miles upstream of Arrowrock Dam along the South Fork of the Boise River. The other two downstream dams (located between Arrowrock Dam and Boise, Idaho) are Lucky Peak Dam and Boise River Diversion Dam. Lucky Peak Dam, a zoned earthfill dam built by the Corps of Engineers in 1955, is located approximately 12 miles downstream from Arrowrock Dam. The Boise River Diversion Dam is a rubble-concrete, weir-type structure located approximately 1 mile downstream from Lucky Peak Dam. This Boise River Diversion dam was originally built to supply power for the construction of Arrowrock Dam, and consists of three 500-kilowatt units that began operation in 1912.

Figure 1: Looking upstream at Arrowrock Reservoir and Dam.

Arrowrock Reservoir is contained by a moderately deep canyon carved by the Boise River, forming a lake with the shape of the letter “y,” with the longest leg being 17 miles long. There are three forks of the Boise River system that enter Arrowrock Reservoir. The North and Middle Forks join upstream of Arrowrock Reservoir to form the northeast leg, and the South Fork forms the southeast leg of the reservoir. The confluence of the northeast (North Fork) and southeast (South Fork) legs is approximately 4 miles upstream of Arrowrock Dam. Flows from Arrowrock Dam are released directly into Lucky Peak Reservoir, which forms the tailwater for Arrowrock Dam.

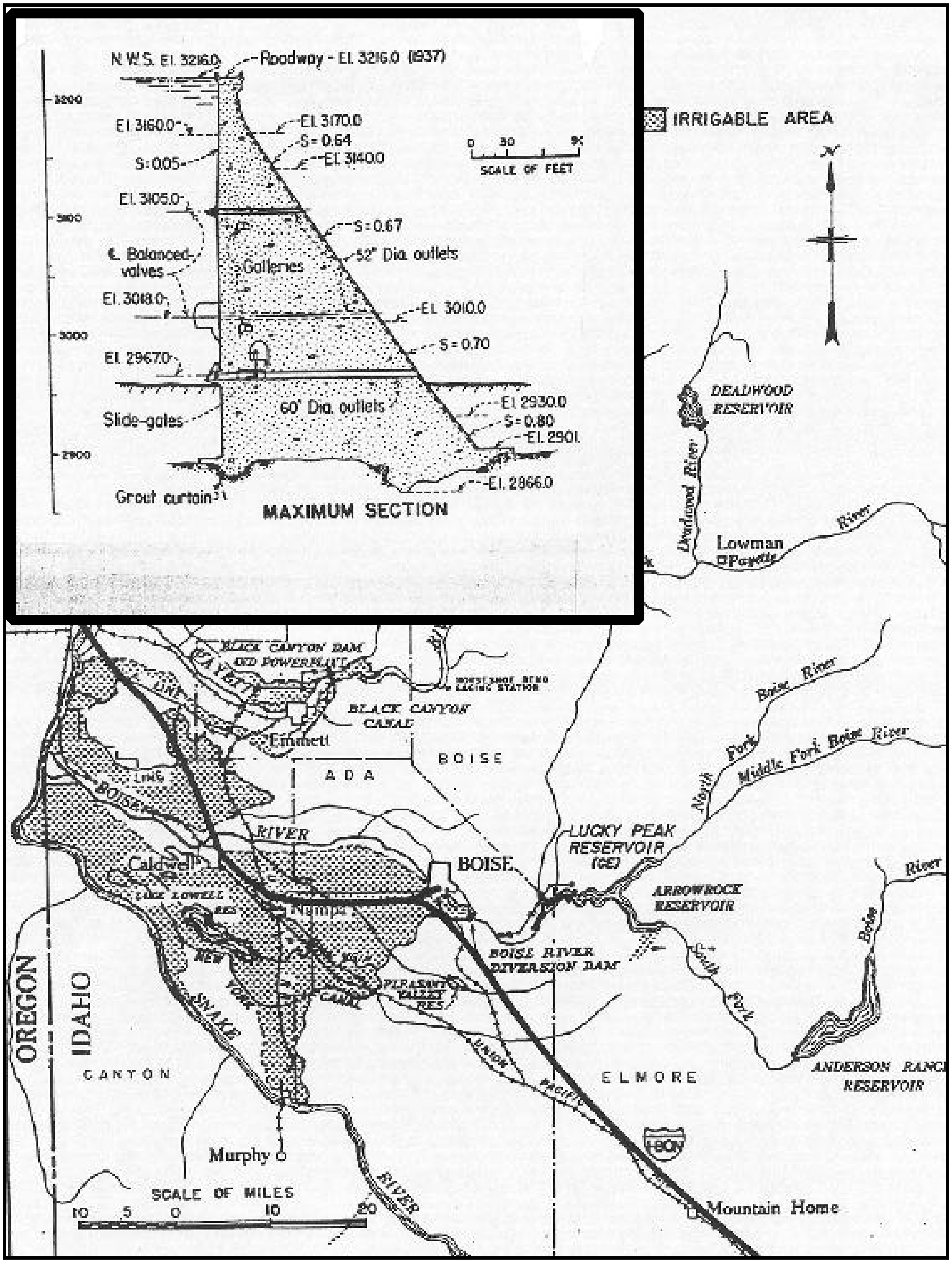

Figure 2: Location map of Arrowrock Reservoir and cross section of dam.

The outlet works for Arrowrock Dam consist of two levels of ensign valves at elevations 3,105 and

3,018, and five sluice outlets with a centerline at elevation 2,967. The sluice outlets are 164 feet long, 60-inches in diameter and each is controlled by a 5- by 5-foot high pressure slide gate, 27.5 feet from the upstream face of the dam. The sluice outlets are unlined except for approximately 20 feet of cast iron transitions extending upstream and downstream of each gate. A trashrack structure, rectangular in shape, is provided over the inlets on the upstream face of the dam. The sluice outlets are numbered one through five, from left to right looking downstream. The sluice gate outlets cannot effectively be operated unless Lucky Peak Reservoir water surface elevation is lowered below the outlet elevation of the sluice gates. An inspection report dated September 23, 1998 recommended that sluice gates No. 3 and 5 be operated only in an emergency situation, but that gates No. 1, 2 and 4 were fully operational. The report also documents that up through 1974, the sluice gates were operated almost every year at heads of 50 feet or less. In 1987 and 1988 , the sluice gates were used to drain Arrowrock Reservoir to the invert elevation of the sluice gates (elevation 2,967) to perform inspections and repairs of the lower ensign valves.

The Arrowrock Dam Outlet Works Rehabilitation Project is proposing to replace the ten lower level ensign valves with clamshell gates located on the downstream side of Arrowrock Dam. After the clamshell gates are installed, the ten upper level ensign valves and the five sluice gates would be abandoned. Two alternatives are being considered for the replacement of the lower ensign valves: Alternative A (replacement without a cofferdam); and Alternative B (replacement with a cofferdam). Under Alternative A, a portion of the existing reservoir sediments could be flushed through Arrowrock Dam. Alternative B would not cause sediment to be flushed from the reservoir.

If the rehabilitation project occurs with Alternative A, the construction period for the replacement of the ensign valves would occur over a 3 year period, with construction work being completed during the non-irrigation season (September 1 to February 28). During the first two years of the project, construction work would be focused on the downstream face of Arrowrock Dam. Lucky Peak Reservoir would be held at elevation 3,000, and Arrowrock Reservoir would be held at elevation 3,110. During the third year of the project, the reservoir level of Arrowrock would be lowered to elevation 3,027 in order to conduct inspection and maintenance on the upstream side of the lower row of ensign valves. If a 5-year flood (4,300 cfs) occurs during Year 3 of the construction period, the sluice gates on Arrowrock Dam would need to be opened to allow flow to pass in order to maintain a constant reservoir water surface elevation. Lucky Peak Reservoir would be drawn down to elevation 3,000 from September 1 to October 31, and further drawn down to elevation 2,962 from November 1 to February 28 to allow for use of the sluice gates in case of a winter flood event. A 1997 sediment survey of Arrowrock Reservoir (Ferrari, 1998) measured a sediment level (just upstream of Arrowrock Dam) at an elevation of 2,987.4, approximately 20 feet above the elevation of the sluice gates (elevation 2,967). The purpose of this sedimentation study is to estimate the quantity of sediment that would be flushed through Arrowrock Dam if the sluice gates are opened during the valve rehabilitation project, and what portion of the sediment will be trapped in Lucky Peak Reservoir.

RESERVOIR HYDRAULICS

The U.S. Army Corps of Engineers' HEC-RAS computer model (version 2.2, Brunner, 1997) was applied to the North and South Fork arms of Arrowrock Reservoir along with the lower 4 miles of the reservoir below the confluence, and to Lucky Peak Reservoir. The HEC-RAS model computes hydraulic parameters such as water surface elevation, depth, and mean velocity for one-dimensional steady flow. The steady flow component of the HEC-RAS model is capable of modeling subcritical, critical, supercritical, and mixed-flow regimes. The model was forced to work in the subcritical flow regime.

The one-dimensional assumption implies that there are no density currents present in the reservoir. If density currents did exist, higher velocities would occur along the reservoir bottom and travel time through the reservoir would shorten. To investigate whether this assumption was valid, evidence of the existence of density currents in Arrowrock Reservoir was evaluated (appendix A). Based on water temperature data, dissolved oxygen measurements, and the thalweg profile of the reservoir, no evidence of density currents in Arrowrock Reservoir was found. Therefore, the assumption that no density currents exist in Arrowrock Reservoir was made for this analysis.

Several types of loss coefficients are utilized in the HEC-RAS model to determine energy losses. Friction losses associated with roughness are set using the Manning's n value. Manning's n values are determined based on the surface roughness, vegetation, channel irregularities, channel alignment, scour and deposition, obstructions, size and shape of the channel, stage and discharge, seasonal change, temperature, and suspended material and bedload. For both reservoirs, a Manning's roughness coefficient of .035 was used. The assumptions of subcritical flow and a reservoir water surface elevation held constant at the dam were used for the downstream boundary conditions.

Lake Elevation and Discharge Data

Lake elevation and discharge data for Arrowrock and Lucky Peak Reservoirs were available from the USBR Hydromet data collection and distribution system accessible through the Internet. Data were obtained for discharges measured along the North Fork of the Boise River near Twin Springs and the South Fork below Anderson Ranch Dam, the discharge release out of Arrowrock Reservoir, and lake elevations for both Arrowrock and Lucky Peak Reservoir from October 1, 1987 to September 30, 1998, water years 1988 through 1998 (figures 3 and 4). This data set represents 11 years of data since the last significant flushing of Arrowrock Reservoir occurred. The lake elevations and inflows of water and sediment since that time have contributed to the development of the 20 feet of sediment (1997 measurement) above the sluice gates at Arrowrock Dam.

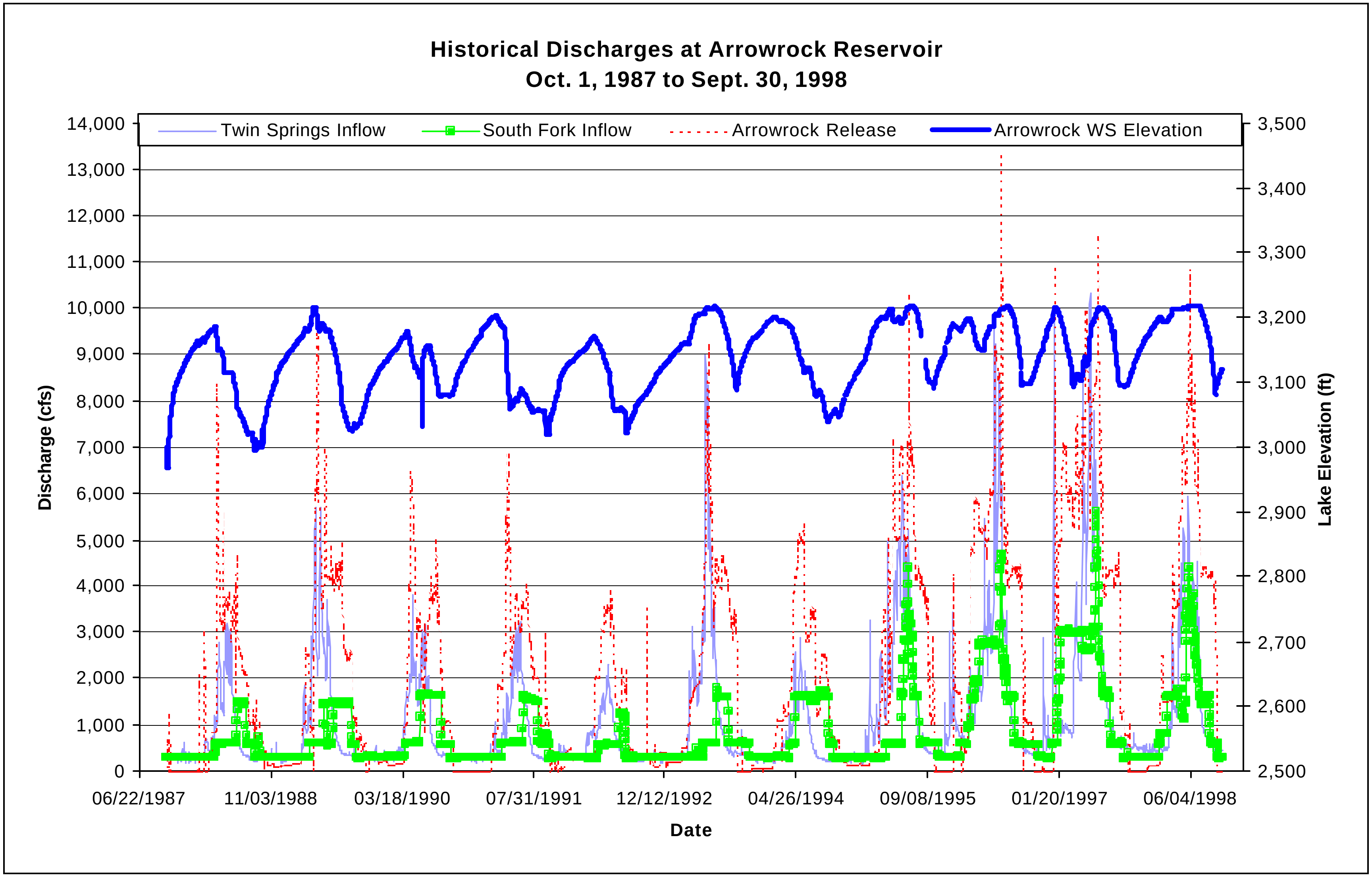

Figure 3: Historical discharges at Arrowrock Reservoir from October 1, 1987 to September 30, 1998.

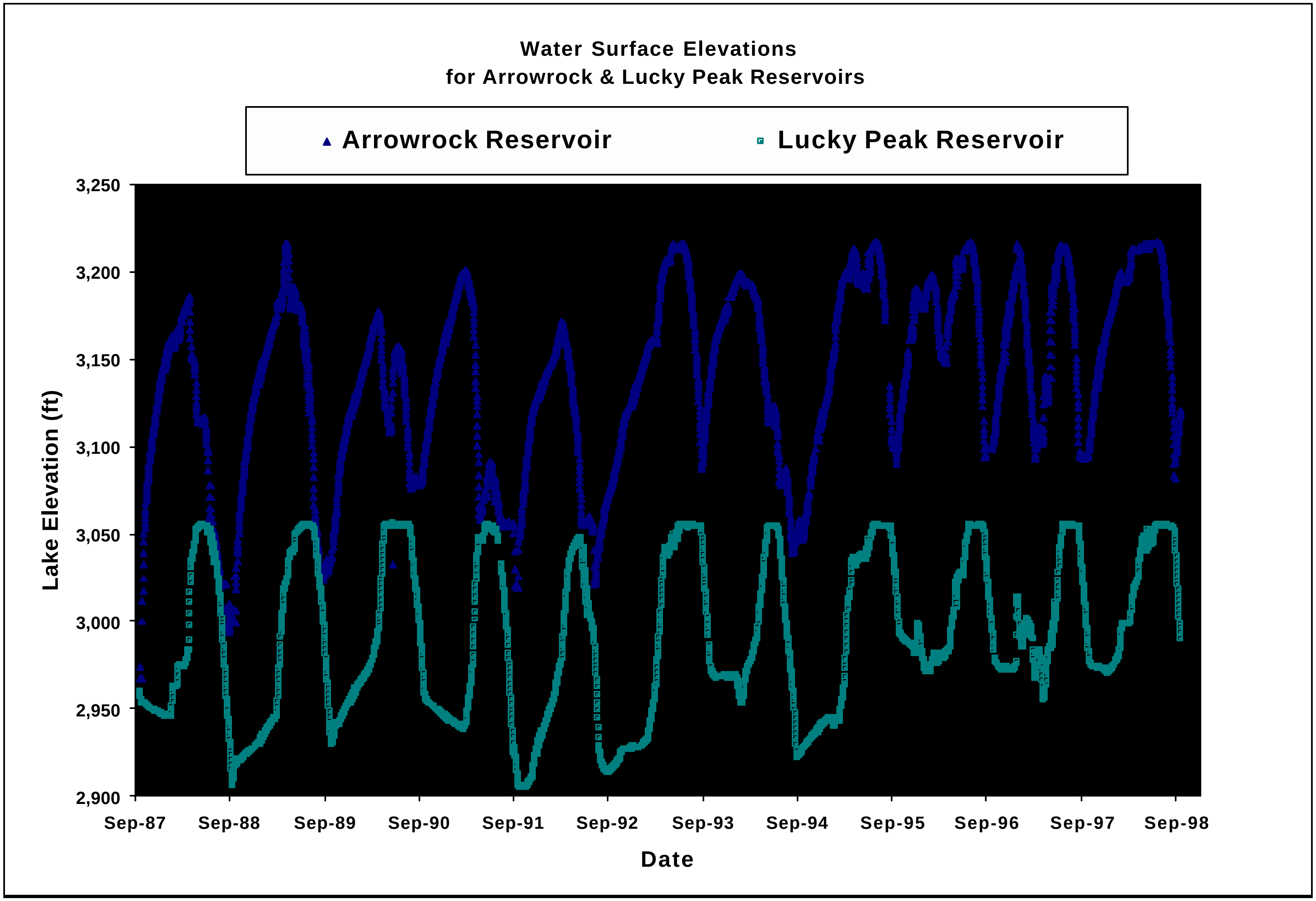

Figure 4: Historical water surface elevations for Arrowrock and Lucky Peak Reservoirs from October 1, 1987 to September 30, 1998.

Under Alternative A, specific lake elevations have been set for both Arrowrock and Lucky Peak Reservoirs to maintain irrigation requirements and allow replacement of the lower ensign valves to take place (table 1). During Year 1 and 2 of the construction, Arrowrock must be held at a high enough water surface elevation (3,110) to pass flow through the upper valves, and Lucky Peak must be held below the outlet of the lower valves (elevation 3,000) to allow maintenance on the downstream side of the valves. During Year 3, Arrowrock must be partially drawn down and held below the bulkheads on the upstream side of the lower valves (elevation 3,027). This partial drawdown will allow construction on the upstream face of the dam, and the valves which don't have bulkheads to be used for day to day discharge operations. If a 5-year winter storm event or greater were to occur, the sluice gates on Arrowrock Dam would be operated in conjunction with the lower valves to maintain a reservoir level at elevation 3,027 (to avoid affecting construction activities). For Year 3, Lucky Peak will be held below the outlet of the lower valves for 2 months (elevation 3,000), and then lowered below the outlet of the sluice gates (elevation 2,962) for the remainder of the construction period to allow use of the sluice gates in case of a winter flood event.

Table 1: Designated lake elevations for 3 year valve replacement project under Alternative A.

September 1 construction start	Arrowrock Lake Elevation	Lucky Peak Lake Elevation
Year 1 and 2: Sept. 1 to Feb. 28	3,110	3,000
Year 3: Sept. 1 to Oct 31	3,027	3,000
Year 3: Nov. 1 to Feb. 28	3,027	2,962

Arrowrock Hydraulic Model

The purpose of modeling the hydraulics in Arrowrock Reservoir was to develop a range of water travel times through the reservoir and typical velocities representative of the last 11 years since the sediment flushing event in 1987. On average in Arrowrock Reservoir, low discharges are typical during the months of August to the end of February, although short duration winter storm events do occur. High flows in longer duration usually occur between the months of March to the end of July. For modeling purposes, the eleven years of discharge data was split into low flow and high flow categories. Minimum, average, and maximum values for each period of record were computed for the North and South Fork inflows (table 2). Discharges for the lower reservoir were computed by summing the inflows from both upper reservoir arms for the minimum and average flow values, and taking the larger of the two peak values for the maximum flow profile. The boundary condition for each flow profile was a historical lake elevation recorded at Arrowrock Dam corresponding to the specified flow value.

Cross sections for the Arrowrock Reservoir model were developed utilizing the 1997 sedimentation survey data (Ferrari, 1998). To develop water surface profiles, twenty-three cross sections were used to model the North Fork arm, and eighteen cross sections were used to model the lower 4 miles of the reservoir below the confluence of the North and South Forks of the Boise River (figure 5). The South Fork arm was also modeled using twenty-three cross sections, however, it is not analyzed in detail because the South Fork is not a significant source of sediment during the construction period. This is because the majority of the sediment inflow from the South Fork is trapped by Anderson Ranch Dam.

Table 2: Discharge and water surface elevation input for Arrowrock Reservoir Hydraulic Model.

Historical Flow Data: Oct. 1, 1987 to Sept. 30, 1998	Low Flow Period (Aug. 1 to Feb. 28)				High Flow Period (Mar. 1 to July 31)			
	North Fork (cfs)	South Fork (cfs)	Below confluence (cfs)[1]	Water Surface (feet)	North Fork (cfs)	South Fork (cfs)	Below confluence (cfs)[2]	Water Surface (feet)
Minimum Period Flow	153	262	415	3,111	255	278	533	3,031
Mean Period Flow	446	499	945	3,123	2,073	1,306	3379	3,159
Maximum Period Flow	9,820	3,040	9,820	3,215	10,300	5,590	10,300	3,172

[2] Discharges for the lower reservoir were computed by summing the inflows from both upper reservoir arms for the minimum and average flow values, and taking the larger of the two peak values for the maximum flow profile.

Because of the varying lake elevation in Arrowrock Reservoir, the hydraulics are dependent not only on the inflow, but also on the capacity of the reservoir. At each reservoir elevation, there is a critical point where the flow conditions change from riverine flow to reservoir flow conditions. For example, at a lake elevation of 3,031 the majority of flow can be characterized as riverine flow. At a much higher water surface elevation of 3,172 only the 2 ½ miles at the upstream end of the reservoir are riverine flow, and the remaining 9 ½ miles are reservoir flow. The riverine areas have much lower water depths and, therefore, higher velocities than the reservoir areas. The computed average velocities from the model can be used to determine water travel times through the reservoir for both riverine and reservoir flow conditions.

<u>Lucky Peak Reservoir Model</u>

The purpose of modeling Lucky Peak Reservoir was to determine the reservoir hydraulics during the valve replacement project. Of particular interest were the hydraulics during a winter storm event in Year 3 when the sluice gates on Arrowrock Dam would be operated releasing water and sediment into Lucky Peak Reservoir. Discharges were modeled to represent the 5- and 10-year winter storm events, along with the historical average and peak discharges. The downstream boundary condition for each construction period was the Lucky Peak lake elevation designated for Year 3 of the valve replacement project under Alternative A (table 1). Under Alternative A,

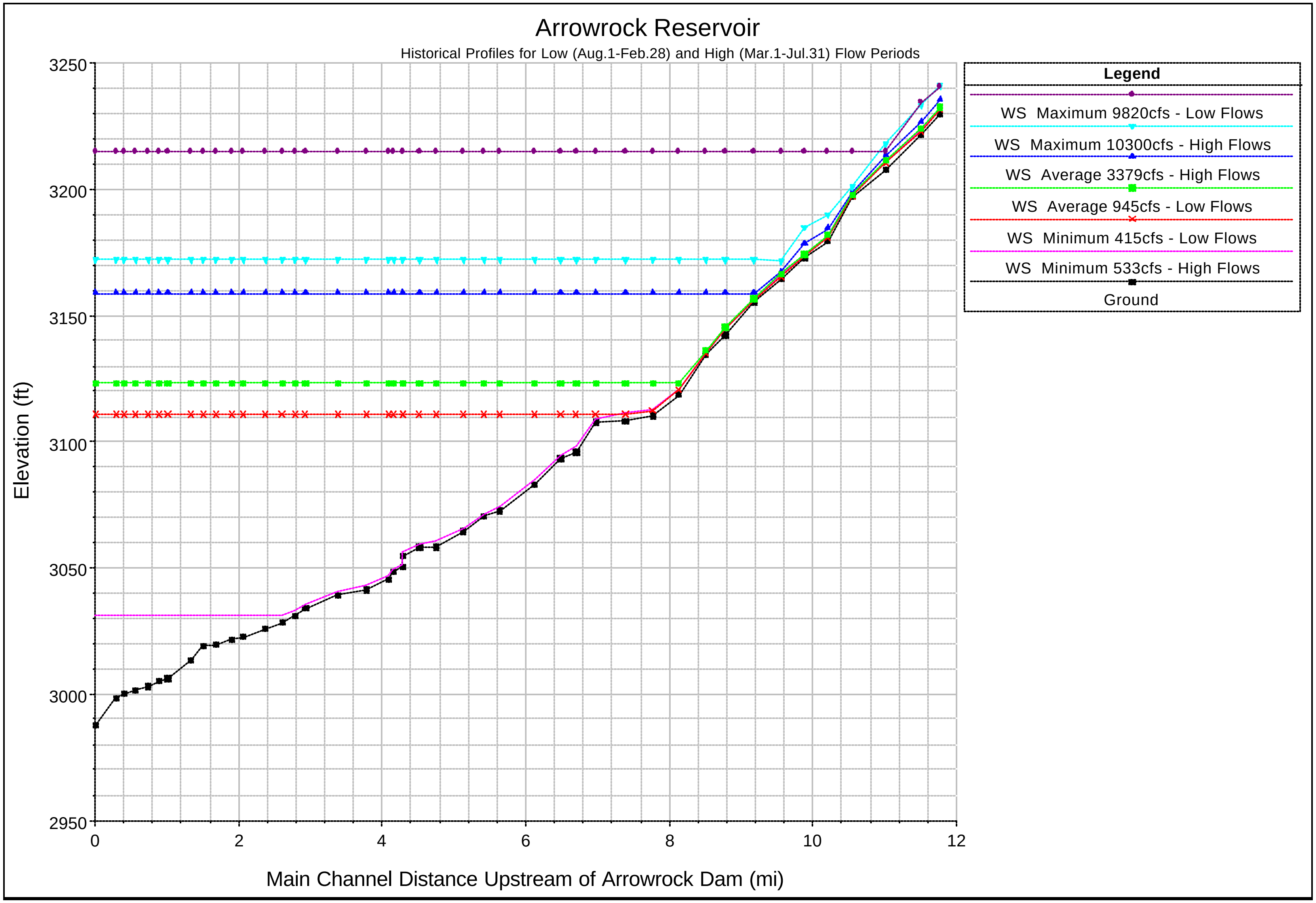

Figure 5: Computed water surface elevation profiles for Arrowrock Reservoir based on historical data from October 1, 1987 to September 30, 1998.

Lucky Peak will be held at elevation 3,000 during September 1 to October 31 of Year 3, and will be further drawn down to elevation 2,962 between November 1 to February 28.

Table 3: Discharge and water surface elevation input for Lucky Peak Hydraulic Model for Year 3 of Valve Replacement Project.

Historical Flow Data: Oct. 1, 1987 to Sept. 30, 1998	Average Period Flow (cfs)	Peak Period Flow (cfs)	5-Year Storm Event (cfs)	10-Year Storm Event (cfs)	Lucky Peak Designated Water Surface Elevation (feet)
Sept. 1 to Oct. 31	650	4,217	4,300	6,200	3,000
Nov. 1 to Feb. 28	568	10,866	4,300	6,200	2,962

Sediment-range data for Lucky Peak Reservoir was obtained from the Walla Walla District of the Army Corps of Engineers. To develop water surface profiles, seventeen cross sections were modeled between Arrowrock and Lucky Peak Dams (figure 6). The cross sections utilized in the model were surveyed in 1994.

Water Travel Times

The sediment trap efficiency for each reservoir depends, in part, on the travel time of water through the reservoir. As water velocities through the reservoir decrease, the travel time of water becomes longer, and the sediment trap efficiency becomes greater. The travel time of water through Arrowrock and Lucky Peak Reservoirs was determined using the mean velocity computed at each of the cross sections in the hydraulic model. The travel time from one cross section to the next was computed by dividing half of the distance between the cross sections by the upstream cross section velocity, dividing the other half of the distance by the downstream cross section velocity, and then adding the two travel times together.

For Arrowrock Reservoir, the travel time through the upstream most 4 miles of the North Fork arm takes only a matter of hours (figure 7). The remaining 8 miles takes anywhere from 2 days to 6 weeks depending on the amount of inflow and lake elevation. For each profile, at the location where the flow conditions change from a river to a reservoir, the travel time begins to increase at a significant rate. For low lake elevations (near the average annual minimum of 3,043), channel type flow conditions are dominant for the majority of the reservoir until the last 2 or 3 miles upstream from the dam where the water surface flattens out (figure 5). At this low elevation with a low inflow, the water travel time was only 2 ½ days to go the distance of the entire reservoir. During periods of peak flows, travel time was less than 2 weeks regardless of lake elevation. During low flows combined with lake elevations near or greater than the average annual mean of 3,139, travel times began increasing.

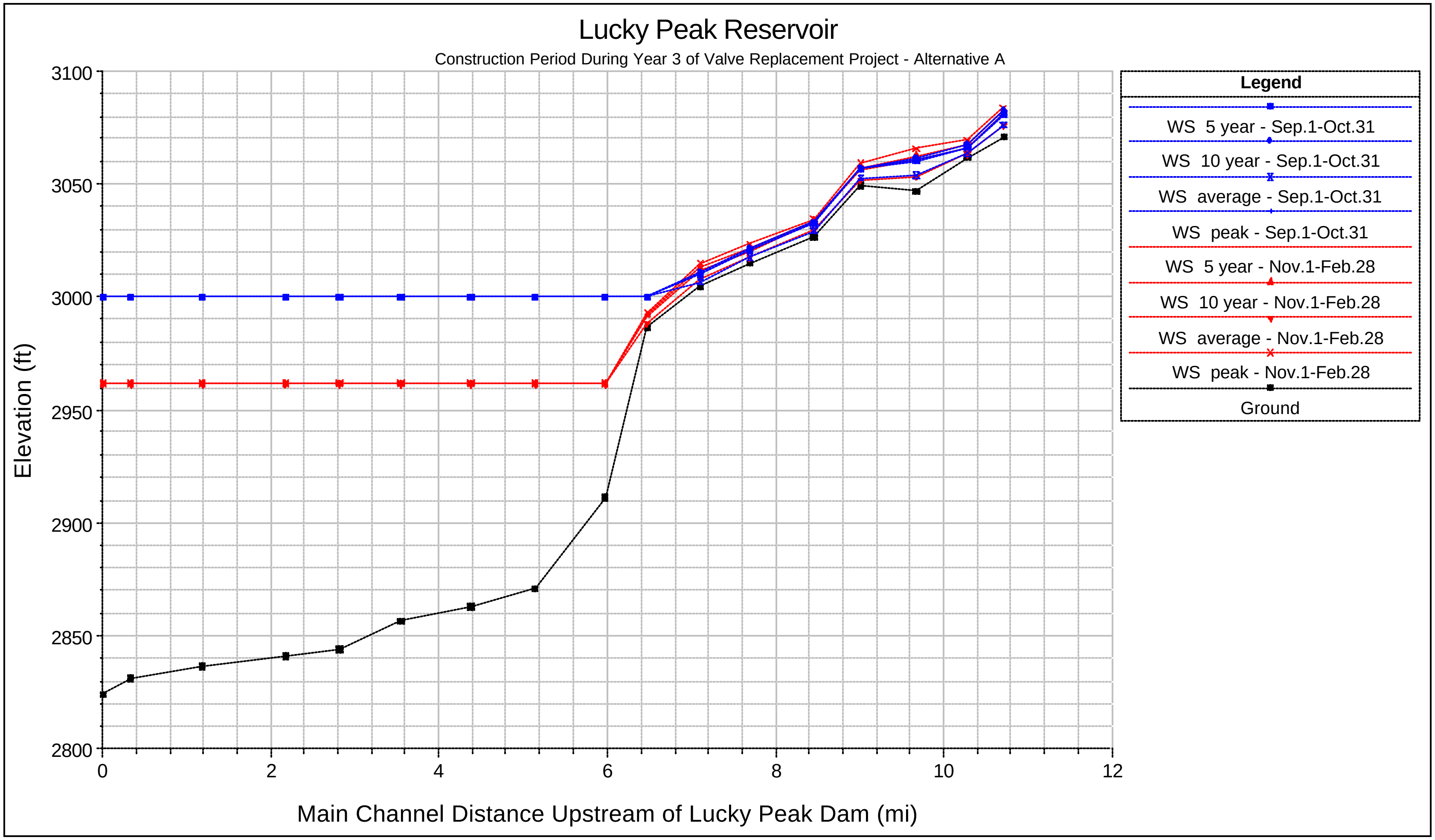

Figure 6: Computed water surface elevation profiles for Lucky Peak Reservoir during construction period of Year 3 of proposed valve replacement (Alternative A) on Arrowrock Dam.

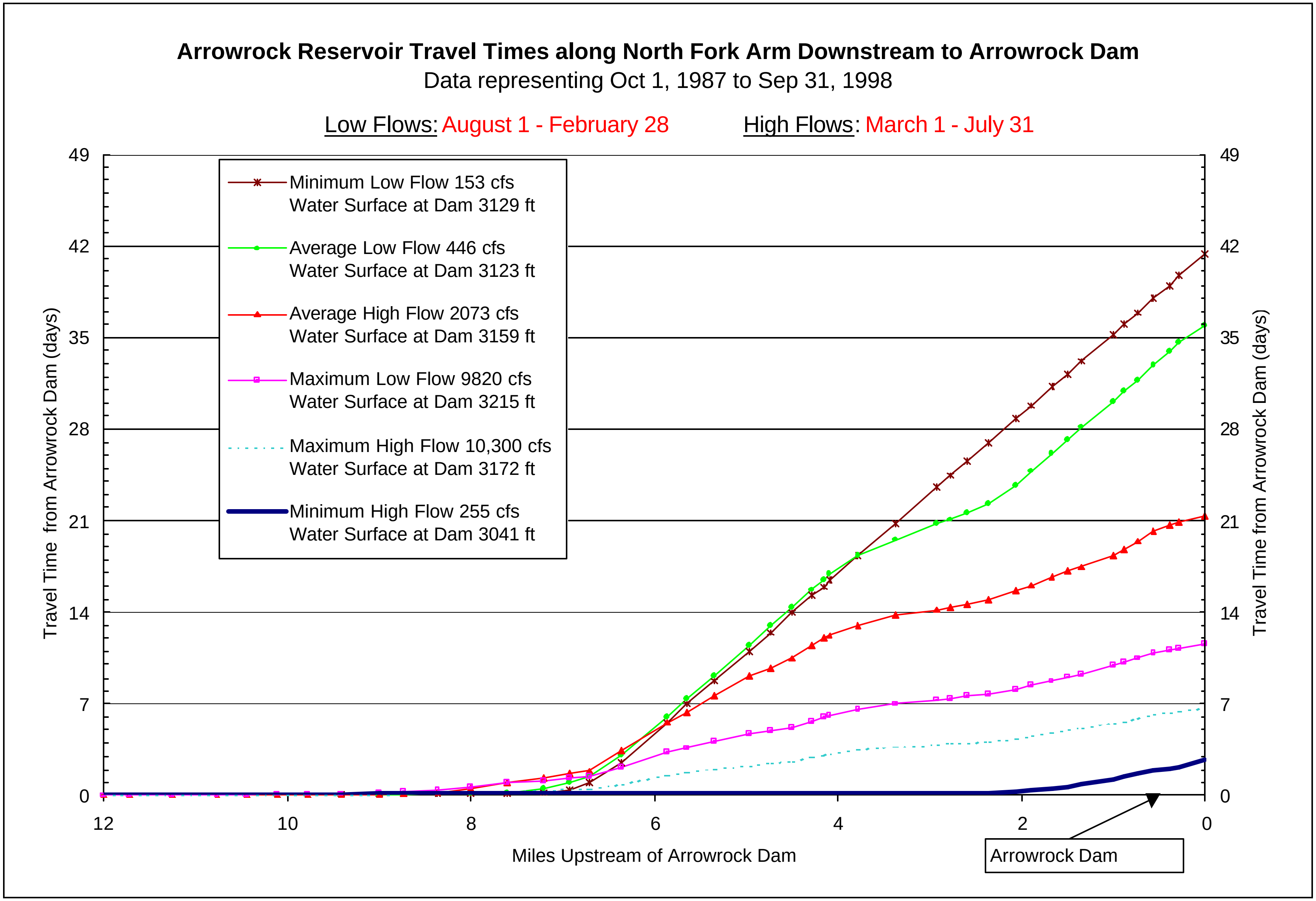

Figure 7: Water travel times for Arrowrock Reservoir.

To better define the dependence of travel time on both inflow and lake elevation, the same minimum, average, and maximum discharge values (table 2) were run with the average annual minimum (3,043), mean (3,139), and peak (3,203) water surface elevations on Arrowrock Reservoir (rather than the corresponding lake elevation recorded). A relationship was developed for each modeled profile based on the travel time it took at the various discharges and lake elevations (figure 8). There is a clear relationship between increase in travel time resulting from increases in lake elevation. As the inflow increases, velocities also increase thereby lowering the amount of travel time. Further, the higher the discharge, the less sensitive the travel time becomes to increases in lake elevation. At the 5-year or greater storm and the average annual minimum lake elevation, water travel times are less than 1 day. This indicates that during Year 3 of the valve replacement project when Arrowrock is at elevation 3,027, travel times for water, and possibly sediment, may be as long as the duration of the storm.

For Lucky Peak Reservoir, travel times were developed for Year 3 of the construction period during the first part from September 1 to October 31 (figure 9) where the reservoir will be held at elevation 3,000, and for the second part from Nov. 1 to Feb. 28 (figure 10) where the reservoir will be drawn down to elevation 2,962. During the second period from November 1 to February 28, Lucky Peak Reservoir will be held 32 feet higher than the average annual minimum lake level (elevation 2,930). The average annual mean lake level for Lucky Peak Reservoir is elevation 2,991, and the average annual maximum lake level is elevation 3,055. At the average flows (less than 700 cfs) and regardless of the lake elevation, the travel times through Lucky Peak Reservoir are 5 to 6 weeks. The first 4 ¼ miles downstream of Arrowrock Reservoir takes only a matter of hours. At higher discharges (greater than 3,500 cfs), travel times through the reservoir range between 4 days to 2 weeks dependent on the lake elevation and amount of inflow. The shortest modeled travel time of 4 days occurs when the lake is drawn down to elevation 2,962 and the peak discharge for the period of record of 10,866 cfs is released out of Arrowrock Reservoir.

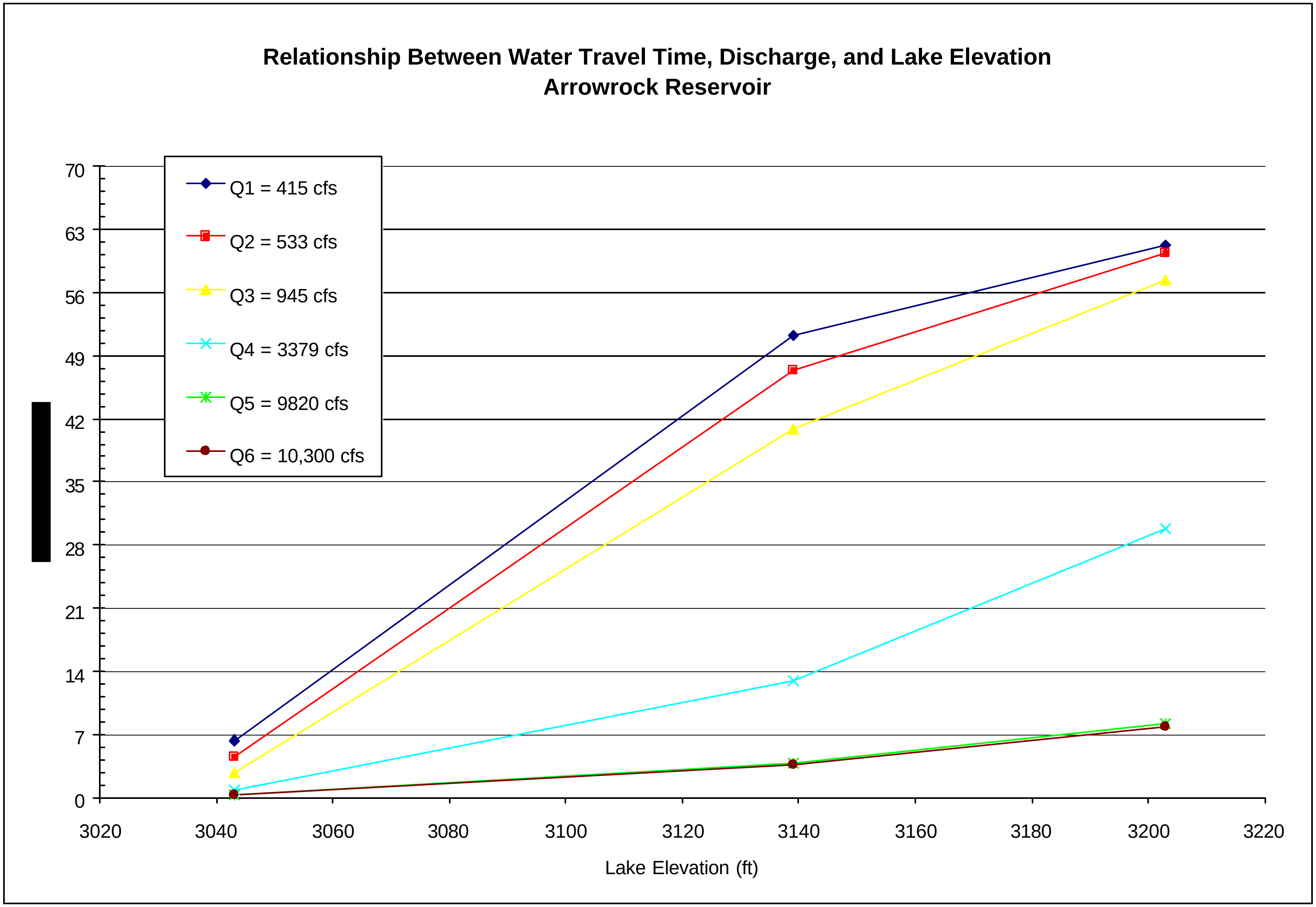

Figure 8: Relationship between lake elevation, travel time, and water inflow for Arrowrock Reservoir.

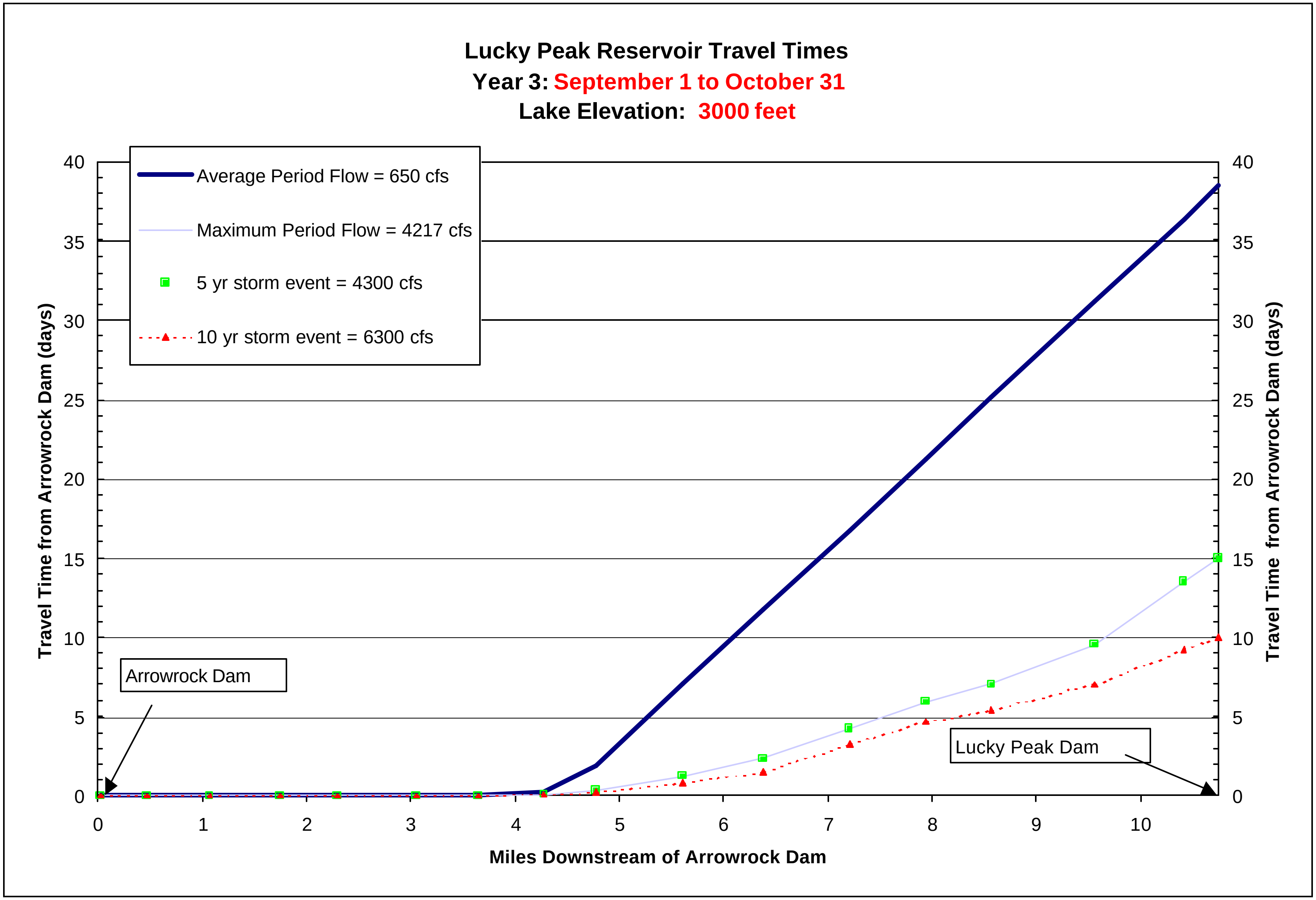

Figure 9: Water travel times for Lucky Peak Reservoir during Sept. 1 to Oct. 31 for Year 3 (Alternative A) of proposed valve replacement on Arrowrock Dam.

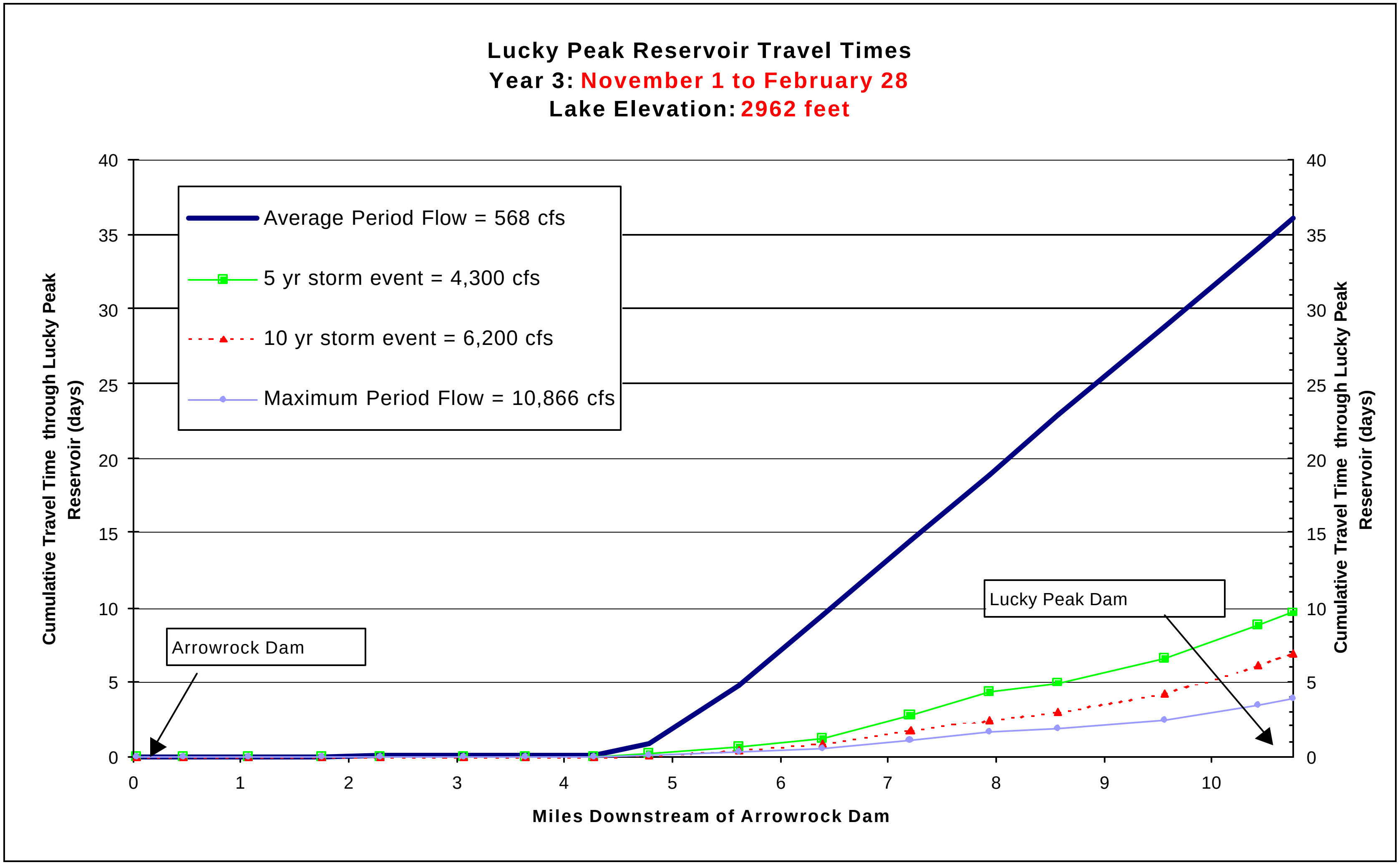

Figure 10: Water travel times for Lucky Peak Reservoir during Nov. 1 to Feb. 28 for Year 3 (Alternative A) of proposed valve replacement on Arrowrock Dam.

SEDIMENTS

Six undisturbed volumetric samples of deposited sediments upstream of Arrowrock Dam were taken on June 18, 1999 (table 4 and figure 11). Each of the samples were analyzed for particle size distribution (table 5) and settling velocity. The particle size distribution results show that the majority of the sediment deposited upstream of Arrowrock Dam is composed of fine grained silts and smaller sized particles. Sample No. 5 is the exception being composed largely of sand. This is most likely due to the location of the sample which was along the south bank of the reservoir (figure 11). For this reason, computations involving sample composition used only the samples representative of the majority of sediment being transported (Sample Nos. 1 to 4 and 6).

Table 4: Sediment samples collected on June 18, 1999, at lake elevation 3,204.9.

Sample No.	Recorded Latitude	Recorded Longitude	Approximate Depth below Water Surface (feet)	Approximate Distance from Arrowrock Dam (feet)
1	43°35' 44"	115°55' 16"	>200	50
2	43°35' 44"	115°55' 15"	220	150
3	43°35' 40"	115°55' 12"	240	450
4	43°35' 38"	115°55' 09"	220	950
5	43°35' 30"	115°55' 07"	210	1,500
6	43°35' 33"	115°54' 59"	230	1,650

Settling Velocity

Settling velocity is primarily a function of the percentage and grain size of the inflowing suspended sediment load that becomes trapped in a reservoir, and also influences the pattern of sediment deposition along the reservoir bottom. A particular grain size of sediment can only be transported in suspension if the flow has enough turbulence to get the sediment in motion. Unfortunately, it was difficult to measure the fall velocity of the fine particles (silt and clay) because of their cohesive properties. However, for each of the six samples, the standard fall velocity was measured for the small percentage of sediment that was sand size (.062 mm or larger). From the measured terminal fall velocity, the average critical velocity at incipient motion (Yang, 1996) was computed as follows:

$$V_{cr} = 2.05\omega$$

where:
V_{cr} = average critical velocity at incipient motion
w = terminal fall velocity

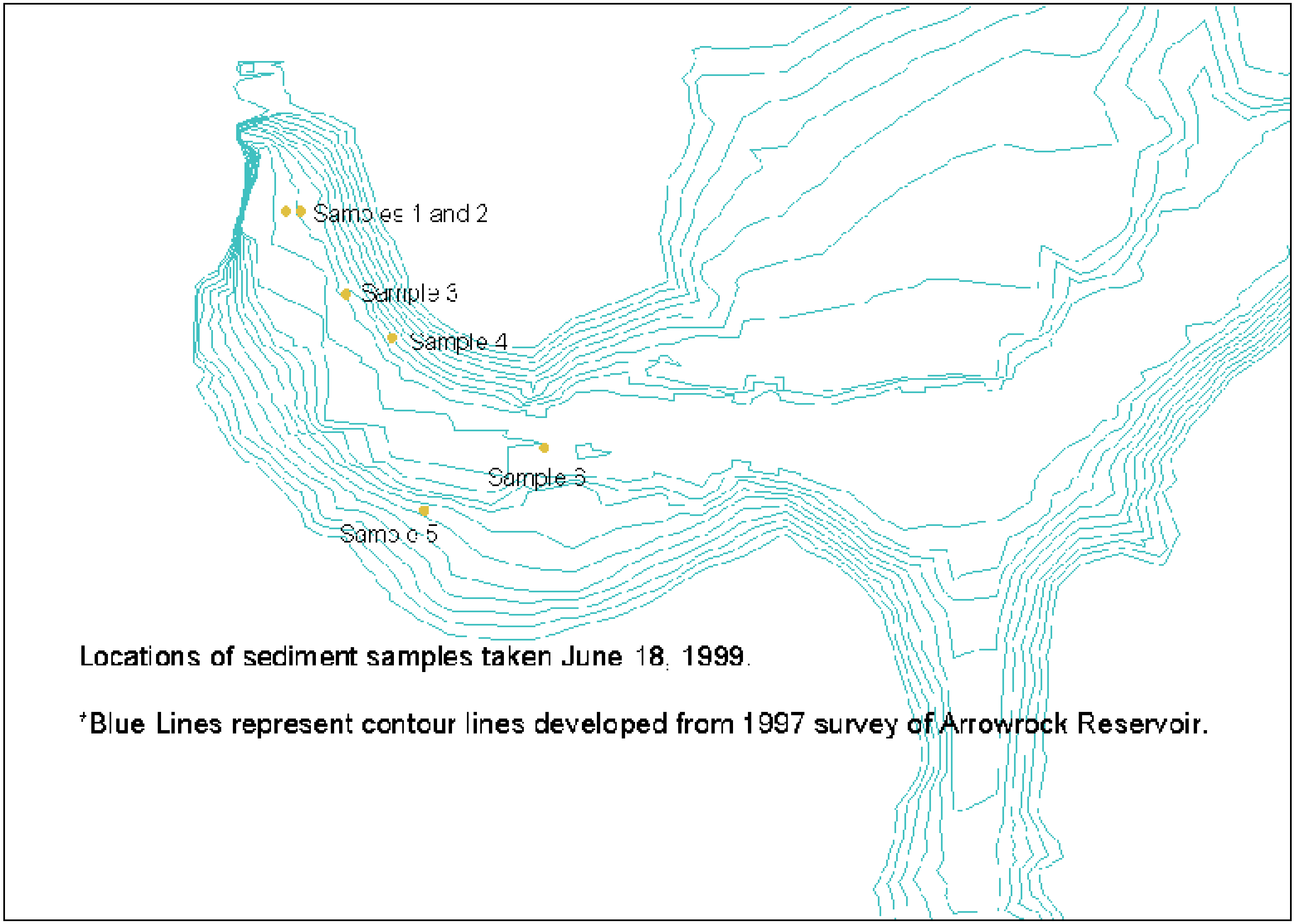

Figure 11: Locations of sediment samples upstream of Arrowrock Dam.

Table 5: Particle size distribution of sediment samples collected in Arrowrock Reservoir.

	Clay	Very Fine Silt	Fine Silt	Medium Silt	Coarse Silt	Very Fine Sand	Fine Sand	Medium Sand	Coarse Sand	Very Coarse Sand	Granule
Grain Size in mm	< .004	.004 - .008	.008 - .016	.016 - .031	.031 - .062	.062 - .125	.125 - .250	.250 - .500	.500 - 1.000	1.000 - 2.000	2.000 - 4.000
Sample #	Cumulative Percent Finer Than Size Indicated										
1	15.8	28.7	58.5	80.6	92.8	95.5	99.1	99.5	99.8	99.9	99.9
2	19.7	33.6	59.2	76.1	88.3	89.7	92.7	94.1	94.6	95.7	100
3	15.4	26.5	55.3	85.1	97.7	99.1	99.6	99.7	99.8	99.9	100
4	25	41.6	70.9	90	99.6	99.8	99.9	100	100	100	100
5	*4.6*	*7.7*	*15.1*	*21.8*	*24.4*	*27.4*	*30.8*	*34.5*	*39.9*	*57.1*	*100*
6	24.2	39.4	67.4	89.4	98.2	99.0	99.7	99.9	99.9	99.9	99.9
Average*	**20.0**	**34.0**	**62.3**	**84.2**	**95.3**	**96.6**	**98.2**	**98.6**	**98.8**	**99.1**	**100**

*Average of samples 1,2,3,4 and 6. Sample 5 was excluded from average due to location outside of main channel and large composition of coarser materials not representative of other samples.

The average critical velocity at incipient motion represents the water velocity needed to force a sediment particle into motion. The average computed critical velocity was .03 to .06 ft/sec for very fine to coarse sand, .12 ft/sec for very coarse sand, and 1.06 ft/sec for granule sized sediment. Although the sand sized particles represent only a small portion of the accumulated sediment upstream of the dam, much of the deposits along the margin of the reservoir may be of this particle size as shown in the particle size analysis of Sample No. 5. Average velocities computed in the hydraulic model did reach greater than 1 ft/sec in riverine channel flow areas, but on average did not reach high enough to move sand sized particles or larger in the reservoir area unless a high inflow, such as a storm event, was modeled.

Dry Specific Weight of Sediment Deposits

In a reservoir, the dry specific weight of deposited sediment changes over time due to accumulation of new sediments, consolidation, and the manner in which the reservoir is operated. The density of sediment deposits in a reservoir can be estimated based on the percentages of particle grain sizes in the material, the initial weights of each grain size, and the type of reservoir operation (based on how often the sediment is submerged). The equation for determining the specific weight of a sediment sample is as follows (Strand and Pemberton, 1982):

$$W = (W_c P_c) + (W_m P_m) + (W_s P_s)$$

where:

W = specific weight of sediment sample

W_c, W_m, W_s= the initial weights for clay, silt, and sand, respectively, based on Lara and Pemberton (1963)

P_c, P_m, P_s = the percentages of clay, silt, and sand, respectively, for the sediment sample

Arrowrock Reservoir can be classified as a type 2 operation reservoir, which means there is normally moderate to considerable reservoir drawdown (Strand and Pemberton, 1982). Initial specific weights were determined for clay (35 lbs/ft^3), silt (71 lbs/ft^3), and sand (97 lbs/ft^3) based on a type 2 reservoir operation. The average percentages of clay, silt, and sand in the sediment deposit upstream of the dam were determined from the results of the particle size distribution analysis (table 6). Based on the initial specific weights and percentages of sediment sizes, a specific weight of 65.1 lbs/ft^3 was computed for the accumulated sediment upstream of Arrowrock Dam.

$$W = (35\frac{\text{lbs}}{\text{ft}^3} \times .20) + (71\frac{\text{lbs}}{\text{ft}^3} \times .75) + (97\frac{\text{lbs}}{\text{ft}^3} \times .05)$$

$$W = 65.1\frac{\text{lbs}}{\text{ft}^3}$$

Table 6: Percent clay, silt, and sand in each sediment sample taken upstream of Arrowrock Dam.

Sample Number	% Clay, P_c	% Silt, P_m	% Sand, P_s
1	15.8	77.0	7.2
2	19.7	68.6	11.7
3	15.4	82.4	2.2
4	25.0	74.6	0.4
5	*4.6*	*19.8*	*75.6*
6	24.2	74.1	1.7
Average[2]	**20.0%**	**75.3%**	**4.6%**

[2] Average of samples 1,2,3,4 and 6. Sample 5 was excluded from average due to large composition of coarser materials not representative of other samples.

AGGRADATION AND TRAP EFFICIENCY

A hydrographic survey for Arrowrock Reservoir was completed in 1915 (the year the dam was built), 1947, and 1997. Comparing the change in elevation of the channel thalweg from 1915 to 1997 reveals sediment deposition patterns along the length of the reservoir (figure 12). The North Fork arm of Arrowrock Reservoir extends to 12.75 river miles upstream of Arrowrock Dam. The confluence of the North and South Fork arms of the Boise River occurs at approximately 4 miles upstream of Arrowrock Dam. The accumulation of sediment that has occurred in the lower portion of the reservoir, and upstream along the North Fork arm, has been uniformly deposited. In other words, the sediment has accumulated approximately 10 feet in depth since 1947 along almost the entire channel bottom. One exception occurs just upstream of the dam where more than 20 feet of sediment has accumulated, and another upstream of RM 7 along the North Fork arm where a delta deposit can be seen. Typically, delta deposits indicate coarse sediment deposition, whereas the finer sediments are more prominent in the lower portion of the reservoir.

Once water travel times for the reservoirs have been established, the release or trap efficiency of a reservoir can be estimated using two methods cited in literature (Morris, 1998). The sediment release efficiency of a reservoir is the mass ratio of the released sediment to the total sediment inflow during a specified single-event storm or long term time period. The sediment trap efficiency (equal to 1 - release efficiency) of a reservoir is an estimate of the amount of sediment trapped in a reservoir over a specified time period. The first method, developed by Churchill, is an empirical relationship based on sediment release efficiency typically used for a single-event storm. The second method, developed by Brune, is typically used for estimating long-term trap efficiency in normally impounded reservoirs. Both methods integrate the ratio of reservoir outlet capacity to inflow, and neither method specifically considers sediment load or the configuration at the dam. However, Churchill did develop two separate curves for estimating

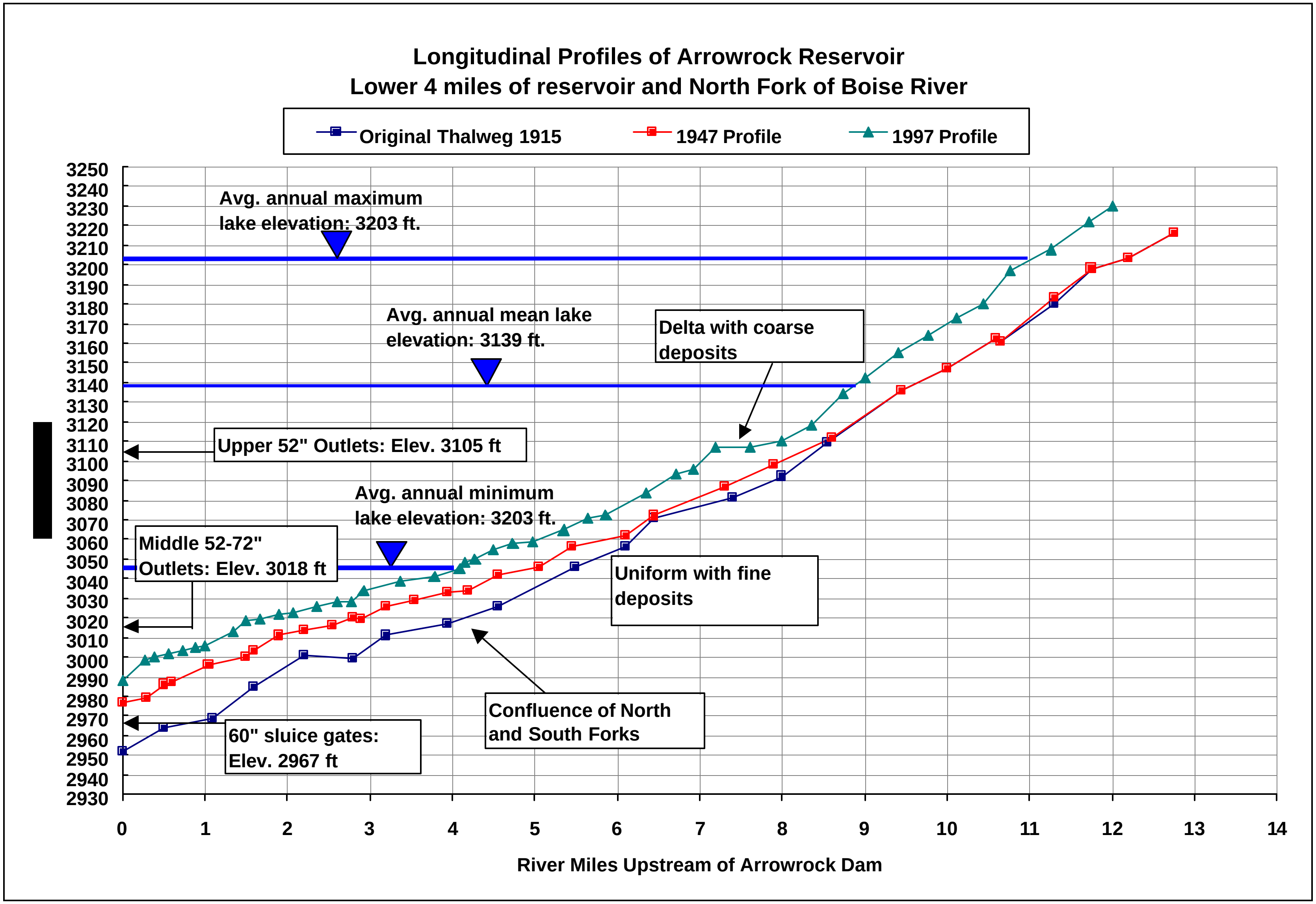

Figure 12: Longitudinal thalweg profiles of North Fork of Boise River to Arrowrock Dam.

sediment release efficiency based on the origination of the sediment load. One curve can be used to approximate fine silts discharged from an upstream reservoir (grain sizes on average smaller than .016mm) while the second curve can be used to approximate local silt (grain sizes typically larger than .016 mm). The sediment samples taken upstream of Arrowrock Dam indicate that 62% of the sediment deposited in the river channel is smaller than .016mm
(table 5).

Long Term Trap Efficiency Estimates

As an overall condition, the trap efficiencies of Arrowrock and Lucky Peak were analyzed for the average annual minimum, mean, and maximum water surface elevations using the Brune Method (table 7). This method incorporates the average annual inflow with the capacity of the reservoir at the specified water surface elevation. The trap efficiency is determined to be the quantity of sediment that will be trapped, on average, at each capacity level of the reservoir. At the average to full lake capacities, Arrowrock and Lucky Peak have identical trap efficiencies of 85 to 90%, respectively. This means that above lake elevations of 3,139 for Arrowrock and 2,991 for Lucky Peak, the majority of sediment passing into each reservoir will settle out and not pass through the dams. However, when the reservoirs are drawn down to the average annual minimum water surface, the Brune Method indicates nearly **b** of the incoming sediment will pass through Arrowrock Reservoir and just under ½ of the sediments will pass through Lucky Peak Reservoir.

Table 7: Long term trap efficiencies using Brune Method.

Reservoir Water Surface Elevation (WS) (ft)	Average Annual Inflow[3] (ft^3/yr)	Reservoir Volume (acre-ft)	Trap Efficiency of Reservoir
Arrowrock Reservoir			
Avg. Annual Minimum WS = 3,043	6.2E+10	9,240	35 % trapped
Avg. Annual Mean WS = 3,139	6.2E+10	105,940	85 % trapped
Avg. Annual Maximum WS = 3,203	6.2E+10	248,490	90 % trapped
Lucky Peak Reservoir			
Avg. Annual Minimum WS = 2,930	6.9E+10	24,030	55 % trapped
Avg. Annual Mean WS = 2,991	6.9E+10	116,550	85 % trapped
Avg. Annual Maximum WS = 3,055	6.9E+10	264,480	90 % trapped

[3] Average annual inflow based on historical gage records for water years 1988 to 1998. The additional annual inflow released into Lucky Peak Reservoir is most likely due to ungaged tributary inflow.

Release and Trap Efficiency Estimates During Valve Replacement

The Churchill method was used to determine the sediment release and trap efficiencies for Arrowrock and Lucky Peak Reservoirs during the valve replacement project. For this project, the release and trap efficiencies are of the most interest during an inflow of at least the 5-year storm (4,300 cfs) in Year 3 of construction, because this is the most likely scenario where the sluice gates on Arrowrock Dam would be used. During a storm event, high inflows of water are transported through a reservoir. In addition to increases in water discharge, sediment load will also increase. It is important to note that in Arrowrock Reservoir, short term release efficiency computations assume that the duration of the storm lasts longer than the travel time for water and sediment to reach the dam. For Years 1 and 2 (elevation 3,110), travel time computations for Arrowrock Reservoir indicated water travel times of at least a few days. This is longer than the duration of most winter storm peaks, which typically last only a matter of hours. Further, sediment is transported at a slower rate than water. Therefore, for Years 1 and 2 the release efficiency of Arrowrock Reservoir may be less than computed causing additional sediment to be trapped. During Year 3 (elevation 3,027), computations for Arrowrock Reservoir indicated that water travel times were less than 1 day. This indicates that sediment transported during a storm may indeed reach the dam, particularly if it is reworked from some location in the reservoir close to the dam. Although no evidence of a density current was found for Arrowrock Reservoir, if one did exist the travel times would be quickened, increasing the chance of sediment load transported during a storm reaching Arrowrock Dam. However, the duration of high inflows into Lucky Peak Reservoir are dependent on releases from Arrowrock Reservoir, rather than the duration of the storm. Travel times computed for Lucky Peak during the valve replacement project were a minimum of 4 days. Therefore, for Lucky Peak Reservoir, if the sluice gates on Arrowrock Dam were not kept open long enough to equal the travel times through the reservoir, the trap efficiencies may be even greater than computed.

Arrowrock Reservoir Release Efficiency

For Arrowrock Reservoir, sediment release efficiencies were computed to estimate the percentage of sediment load (transported during a 5- or 10-year winter storm) that will pass through to Lucky Peak if the sluice gates are opened. The release efficiencies were computed for all 3 years of construction using the lake elevations specified for Alternative A and inflows for the 5- and 10-year storm events. For comparison purposes, the release efficiencies during Year 1 and 2 of construction (elevation 3,110) and at the average annual maximum lake elevation (3,203) were also analyzed.

Using the Churchill method, sediment release efficiencies were approximated for local silt (assumed to be .016 mm and coarser), and for fine silt (assumed to be finer than .016 mm) (table 8). At the average annual maximum lake elevation of 3,203, if a 5-year or greater storm event occurs, hardly any of the coarse silt passes through Arrowrock Dam to Lucky Peak Reservoir, and a small portion of the finer silts (20 to 30%) pass through. As the lake elevation is lowered, a much larger portion of the sediments are passed through the reservoir because of the increased velocities, which in turn increases the sediment transport capacity. During Year 3, when the lake is lowered to elevation 3,027 (60 feet above the sluice gates), almost all of the fine and coarse silts brought in by a 5-year or greater winter storm event pass through Arrowrock Reservoir to Lucky Peak Reservoir.

Table 8: Release efficiencies for Arrowrock Reservoir during the valve replacement (Alternative A) based on the Churchill Method.

ARROWROCK	At Average Annual Maximum Lake Elevation		Year 1 & 2 Valve Replacement (Oct. 1 to Feb. 28)		Year 3 Valve Replacement (Sept. 1 to Feb. 28)	
Event	5-year	10-year	5-year	10-year	5-year	10-year
Lake Elevation (feet)	3,203		3,110		3,027	
Inflow (cfs)	4,300	6,200	4,300	6,200	4,300	6,200
Fine Silt Release Efficiency (% passing)	20	30	60	70	>95	>95
Coarse Silt Release Efficiency (% passing)	< 5	10	25	30	80	>95

Lucky Peak Reservoir Trap Efficiency

For Lucky Peak Reservoir, the trap efficiencies were computed to estimate the amount of sediment that will be passed through the reservoir if the sluice gates on Arrowrock Dam are opened during the valve replacement project. The trap efficiencies were computed for all 3 years of construction using the lake elevations specified for Alternative A and inflows for the 5- and 10-year storm events (table 9). In addition, the trap efficiencies for the average and peak flows for both September 1 to October 31 and November1 to February 28 (correlating to 2 separate lake elevations for Year 3) were also computed for comparison purposes. At lake elevation 3,000, the majority of sediment transported into Lucky Peak Reservoir does not pass through unless a 5-year or greater storm event occurs. During a 5- to 10-year storm, approximately **a** to ½ of the finer silts and 15-20% of the coarse silts pass through, respectively. During November 1 to February 28 (in Year 3) when the reservoir is drawn down to elevation 2,962, if a 5-year or greater storm event occurs more than half of the finer silts will pass through Lucky Peak Reservoir and up to ¼ of the coarser silts. If an extremely large release occurs, equivalent to the 10-year storm, more than **b** of the finer silts have the potential to pass through Lucky Peak Reservoir and 30% of the coarser silts. This analysis assumes that the duration of the storm must be longer than the travel time through the reservoir for the sediment to reach Lucky Peak Dam. Further, the assumption is made that the outlet operation of Lucky Peak is such that the sediment has the capability to be flushed out. If no low level outlets are being operated, then there is a much greater potential to trap sediment, particularly just upstream of the dam.

Table 9: Trap efficiencies for Lucky Peak Reservoir during Year 3 of the valve replacement (Alternative A) based on the Churchill Method.

LUCKY PEAK	Year 1,2: Sept.1-Feb. 28 Year 3: Sept. 1-Oct. 31		Year 3: Sept.1-Oct.31		Year 3: Nov. 1-Feb. 28			
Lake Elevation	3,000		3,000		2,962			
Event	5-year	10-year	Avg.	Peak	Avg.	Peak	5-year	10-year
Inflow (cfs)	4,300	6,200	650	4,217	568	10,866	4,300	6,200
Fine Silt Trap Efficiency (% trapped)	65	50	>95	65	>95	10	45	30
Coarse Silt Trap Efficiency (% trapped)	85	80	>95	85	>95	60	75	70

FLUSHING PROCESSES AND VOLUME ESTIMATE

During the third year of the proposed valve replacement, Arrowrock Reservoir will be partially drawn down to elevation 3,027 (from Sept.1 to Feb. 28), 60 feet above the sluice gates. During this construction phase, the sluice gates on Arrowrock Dam would be opened in conjunction with the available lower ensign valves to maintain reservoir level if there is a 5-year flood (4,300 cfs) or larger. The maximum release capacity of all five sluice gates is 4,670 cfs, or 934 cfs per gate. Opening the sluice gates will not only allow water to be passed through Arrowrock Reservoir to Lucky Peak Reservoir, but also sediment. The sources of sediment that may be passed into Lucky Peak Reservoir by opening the sluice gates include sediment transported through Arrowrock Reservoir to the dam during the storm, and sediment flushed out from the deposit upstream of Arrowrock Dam. Volume estimates were computed for the potential sediment flushed from the deposit upstream of Arrowrock Dam if the sluice gates were opened during Year 3 when the reservoir will be partially drawn down. If a substantial amount of debris is lodged up against the trash racks on the sluice gates, the actual amount of sediment flushing may be less than predicted.

The last drawdown of Arrowrock Reservoir occurred during 1987 and 1988 when the reservoir was lowered all the way to the elevation of the sluice gates (2,967 feet) to inspect the lower ensign valves. Video documentation and conversations with observers of the 1987 drawdown indicate large concentrations of grayish sediment being released initially from each sluice gate, and then tapering off within a few hours. A reservoir survey prior to or following the drawdown and subsequent sluice gate flushing was not performed. Since the last flushing event in 1987, the largest inflow that has occurred during September 1 to February 28 (period of valve replacement construction) is 9,820 cfs from the North Fork arm of the reservoir, and the largest release into Lucky Peak Reservoir was 10,866 cfs. If for any reason during the valve replacement the sluice gates remain open resulting in a lowering of the reservoir to the elevation of the sluice gates, the hydraulic and flushing processes will be substantially greater than if the gates are used only to maintain the partial drawdown level. For reference purposes, a separate volume estimate was made for the quantity of sediment that would be flushed through the sluice gates if they remained open until full drawdown of the reservoir was attained.

Scour Volume Estimate for Partial Drawdown (Alternative A)

Based on documentation of sluicing events, the peak concentration of sediment flushing occurs rapidly during the final stages of a full drawdown of a reservoir (figure 13). However, during Year 3 of the proposed valve replacement project, Arrowrock Reservoir will only be partially drawn down to an elevation 60 feet above the bottom outlets. Under conditions where the reservoir elevation is at a constant, partial drawdown level, pressure flushing occurs when the sluice gates are opened. A conical scour cone hole will form upstream of the dam, rather than an extensive scouring of the channel for a long distance upstream as in a drawdown. Further upstream of the dam, sediments may still be eroded but are simply redistributed closer to the dam rather than passing through. Assuming that partial drawdown would have already occurred (at the start of Year 3 construction) before the sluice gates would be opened to release a flood, the major source of sediment sluiced would occur from the reservoir bottom in the vicinity of the sluice gate, with very little being caused from lateral erosion that may occur during a drawdown. Therefore, if the sluice gates are opened, a small portion of sediment from the eroded scour cone may pass through the dam, but extensive sediment evacuation would only occur during full drawdown (elevation 2,967).

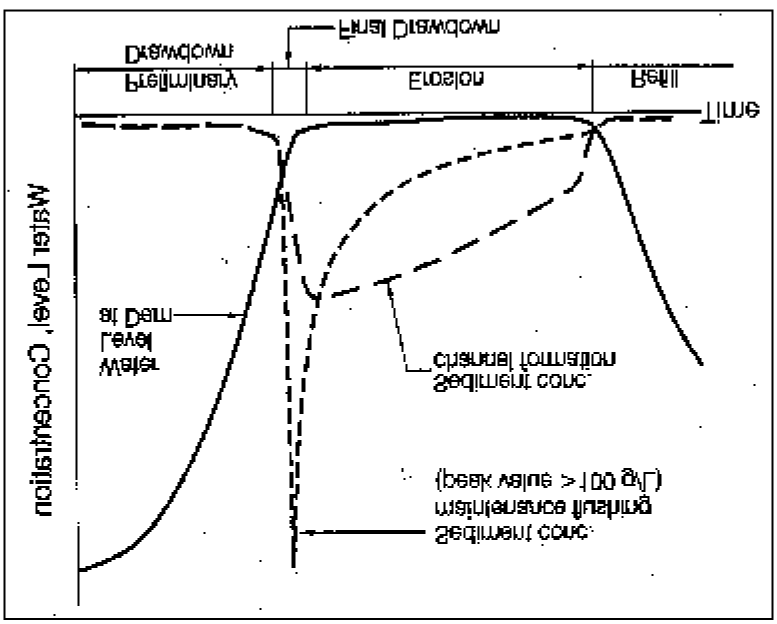

Figure 13: Hydraulic and sediment characteristics for channel formation and channel maintenance flushing events at constant discharge (Morris and Fan, 1998).

Because a scour cone will form upstream of each sluice gate, the overall volume of sediment flushed under partial drawdown is dependent on the number of sluice gates opened, the amount of time they are opened, and the magnitude of the inflowing storm event. It is important to note that scour cone geometry is not fixed and is influenced by changing discharge conditions. As an approximation, the volume of the scour cone can be estimated to be approximately as large as the outlet cross section, and located at the outlet invert elevation. In partially drawn down reservoirs with sediment accumulated against a low-level outlet, if the outlet is opened, the angle of repose can be used to describe the side slope of the cone which is excavated within the sediment. The angle of repose is the slope angle formed with the horizontal at the critical condition of incipient sliding (mobility).

To compute the scour volume, a trapezoidal cross section was estimated at each sluice outlet (figure 14). The bottom width was set equal to the width of the sluice gate diameter (5 feet) and a top width equal to 40 feet, which is approximately 1/5 of the total bottom width of the dam (200 feet). The height of each trapezoidal cross section is dependent on the side slope. Two side slopes were used for comparison - a 1:1 side slope resulting in a height of 17.5 feet, and a 2:1 side slope giving a height of 8.75 feet. The remainder of the sluiced area above where the trapezoid is defined was determined using a rectangle approximation. The maximum height of each scour cone (trapezoid plus rectangle area) is 20 feet at the dam.

To estimate the total volume of scour cone sluiced at each of the five sluice gates, the trapezoid plus rectangle area can be extended a length upstream dependent on the angle of the scour cone. A typical estimate for the angle of repose for the type of grain sizes found in Arrowrock Reservoir is 4 degrees. Based on this angle, each scour cone will extend 286 feet upstream. Based on this approximation, each sluice gate has the potential to produce a scour cone of 1.5 to 2.0 acre-ft of sediment. If all five sluice gates are operated, the total sediment flushed due to scour cone formation is 8.0 to 10.5 acre-ft.

<u>Scour Volume Estimate for Full Drawdown</u>

When a reservoir is completely drawn down to the elevation of the sluicing outlets, a significant portion of sediment will be released for each gate operated (if the outlets have an accumulation of sediment above the invert elevation). Typically, a single main channel will be scoured out through the easily erodible fine sediments while sediments along the reservoir margins remain unaffected. Sediments from the upper pool may be redeposited closer to the dam - particularly in the reservoir area above the lake elevation where velocities are higher. In addition, flushing often produces unstable channel banks which may initiate lateral erosion. The majority of sediment flushing occurs during the final drawdown stages when the reservoir has been completely emptied below the minimum operational level using the bottom outlets (figure 13). Peak sediment concentrations occur rapidly and can reach greater than 100,000 mg/l. After the reservoir has been completely drawn down, and if the bottom outlets remain open, sediment will be gradually flushed out while redistribution of sediment throughout the reservoir occurs. Channel formation often occurs due to the scouring along the channel bottom, particularly if there is a long duration of high inflow.

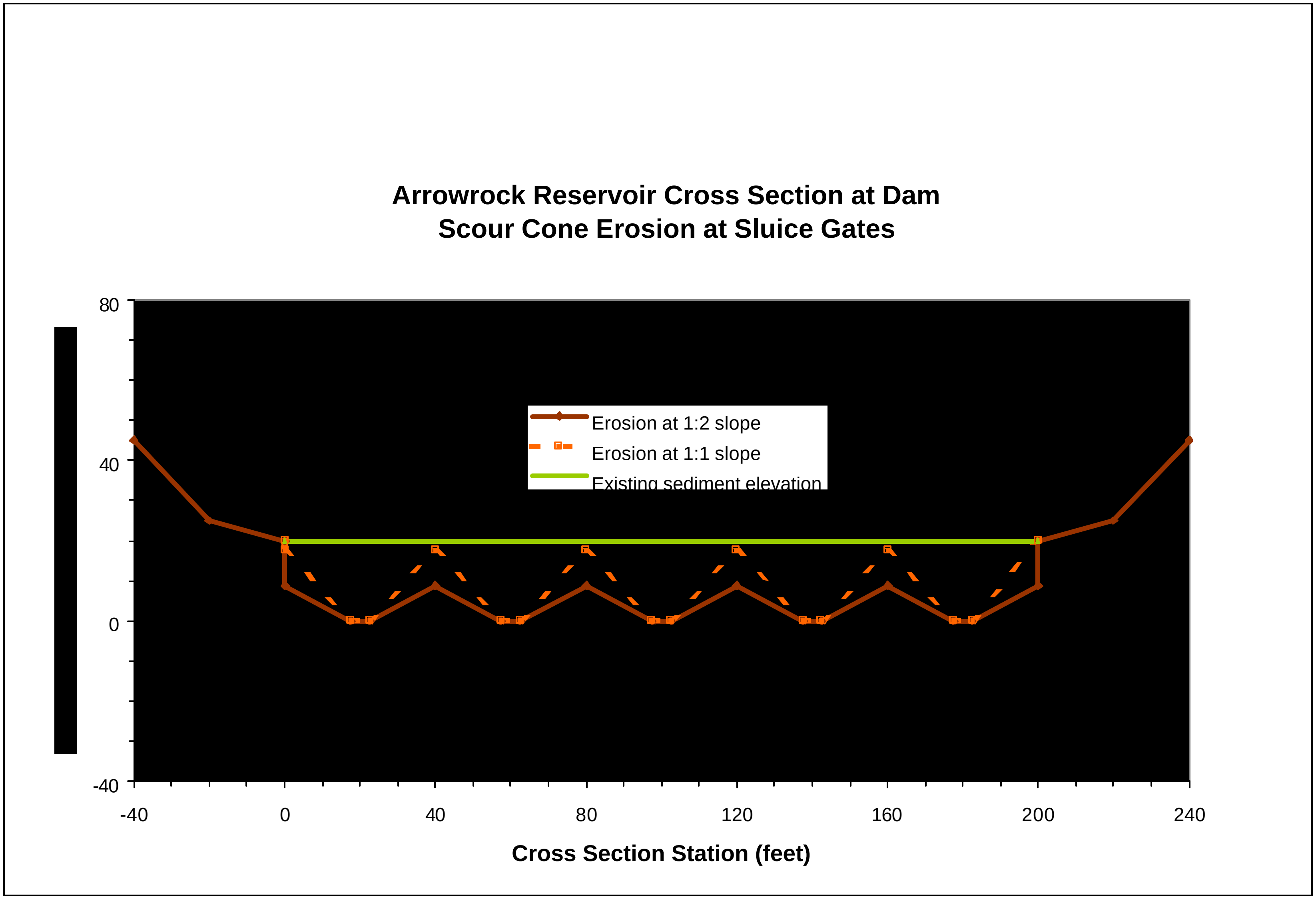

Figure 14: Cross section at Arrowrock Dam developed for a scour cone erosion estimate at each sluice gate.

During a high inflow when extensive redistribution of sediment and channel formation is occurring, a river channel will tend to adjust towards a more stable slope. By estimating the stable channel slope, the upstream extent of the channel scouring can be determined. The upstream extent is determined by projecting the stable channel slope upstream from the sluice gate elevation until it intersects the existing reservoir bottom. The stable channel slope can be approximated by looking at the original 1915 channel profile prior to the reservoir operation (figure 15). Two slopes were estimated in the lower portion of the reservoir based on the existing (1997 survey) steepest slope (.0056) and an average slope (.0039) between Arrowrock Dam and the confluence of the North and South Forks of the Boise River. The shape of the wedge of sediment scoured can be approximated by a trapezoid with a 1:1 slope carved out of each cross section along the reservoir bottom. The average width of the scoured cross section can be approximated by the typical channel width evident in the 1997 contour map - approximately 200 feet. The maximum height of the trapezoidal wedge is the 20 feet of accumulation of sediment just upstream of the dam. Although the channel width may be 200 feet at the upstream end of the scour wedge, the depth of the scoured section will be nearly zero. The area below the outlet elevation of 2,967 feet represents a dead zone of sediment that will not be released if the sluice gates are opened.

A range of volume estimates for the potential sediment volumes that could be sluiced during a 5-year storm event or greater during a complete drawdown situation were computed based on the preceding criteria. These estimates were based on the assumption that all five sluice gates would be operated for the duration of the storm. At the lower end of the range (using the steepest channel slope) the potential sluiced volume during a full drawdown would be 520 acre-ft. At the upper end of the range (using the average channel slope) the estimated sluiced volume during a full drawdown would be 1,250 acre-ft. Therefore, if an emergency or operational failure occurred resulting in the reservoir being lowered to the elevation of the sluice gates using the bottom outlets, the volume of sediment flushed is estimated to be 520 to 1250 acre-ft.

<u>Sediment Trap Efficiencies of Lucky Peak Reservoir</u>

Sediment trap efficiencies correlating to the 5- and 10-year storm events were computed for Lucky Peak Reservoir for the lake elevations (Alternative A) during the valve replacement (table 9). The trap efficiency computations were applied to the scour volume estimates to compute the total volume of sediment that could be trapped in Lucky Peak Reservoir if the sluice gates on Arrowrock Dam are operated during the valve replacement (table 10). For comparison purposes, estimates of the total volume of flushed sediment trapped in Lucky Peak Reservoir were made for both partial and full drawdown scour volume estimates. Volume estimates for sediment trapped during a partial drawdown were combined for the 5- and 10-year floods because of the small magnitude of the numbers relative to the total drawdown estimates.

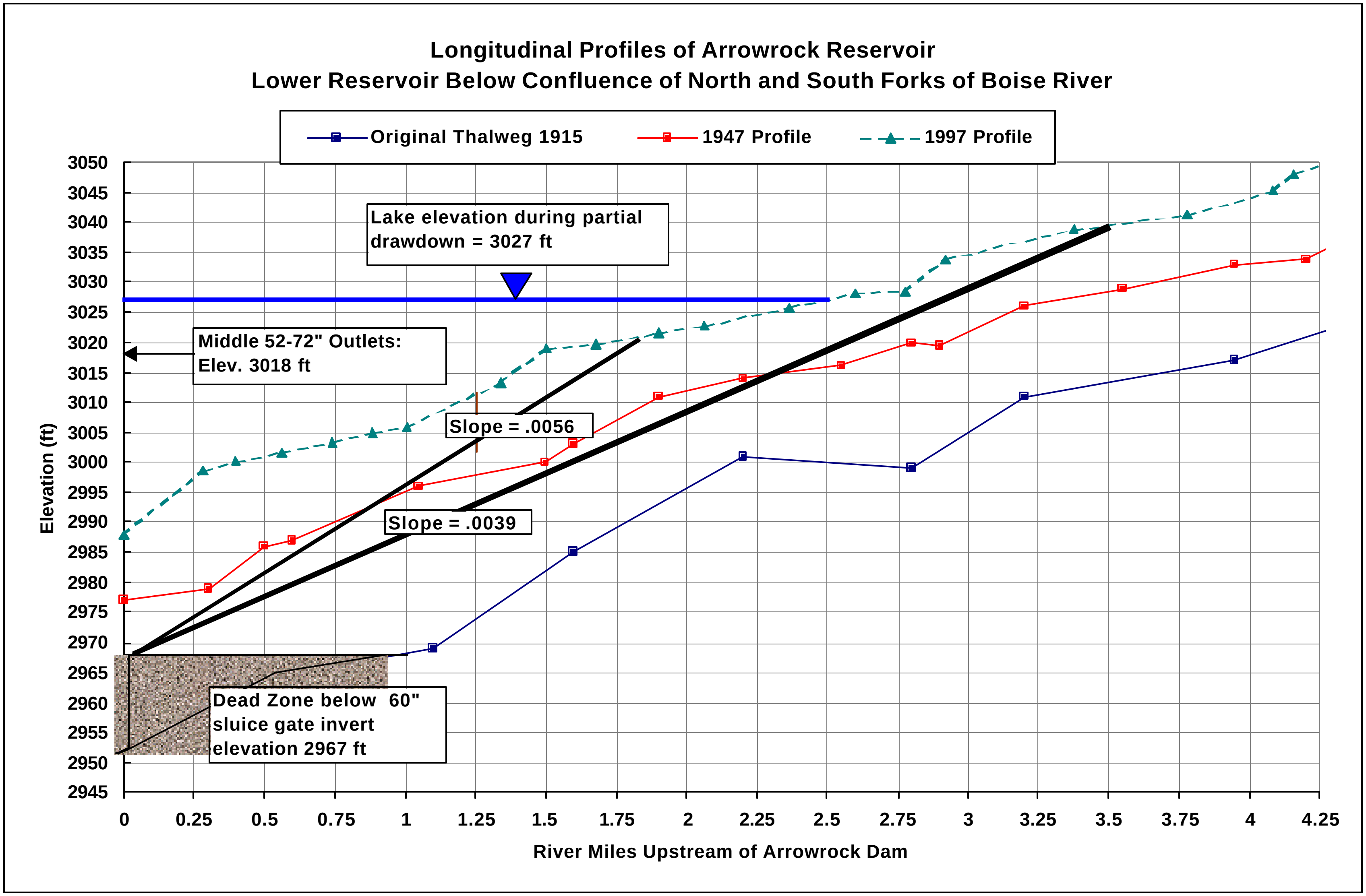

Figure 15: Longitudinal profiles and slope estimates for volume of sediment flushed during a full drawdown to the sluice gates invert elevation at 2967 feet in Arrowrock Reservoir.

Table 10: Volume of sediment trapped in Lucky Peak Reservoir at water surface elevation 3,000 and 2,962, if all five sluice gates on Arrowrock Dam are operated during Year 3 of valve replacement.

LAKE ELEVATION: 3,000							
Sediment Volume Flushed from Arrowrock Reservoir during Sluice Gate Operation (acre-ft)		Volume of Sediment Trapped in Lucky Peak (acre-ft)					
		Fine Silts (<.016mm)		Coarse Silts (>.016mm)		Total Volume Trapped	
Total Drawdown:		5-year	10-year	5-year	10-year	5- to 10-year	
Minimum Wedge	520	210	160	170	160	320 - 380	
Maximum Wedge	1250	505	390	405	380	770 - 910	
Partial Drawdown - Alternative A:		5- to 10-year		5- to 10-year		5- to 10-year	
Minimum Cone	8.0	3.0		2.5		5.5	
Maximum Cone	10.5	4.0		3.5		7.5	

LAKE ELEVATION: 2,962						
Sediment Volume Flushed from Arrowrock Reservoir during Sluice Gate Operation (acre-ft)		Volume of Sediment Trapped in Lucky Peak (acre-ft)				
		Fine Silts (<.016mm)		Coarse Silts (>.016mm)		Total Volume Trapped
Total Drawdown:		5-year	10-year	5-year	10-year	5- to 10- year
Minimum Wedge	520	145	95	150	140	235 - 295
Maximum Wedge	1250	350	235	355	335	570-705
Partial Drawdown -Alternative A:		5- to 10-year		5- to 10-year		5- to 10-year
Minimum Cone	8.0	2.0		2.5		4.5
Maximum Cone	10.5	2.5		3.0		5.5

Additional Sediment Transported During a Flood

Because the sluice gates will only be operated during a 5-year flood event or greater, the volume of sediment being flushed out of Arrowrock Reservoir must also account for the sediment being transported in due to the flood. From January of 1939 to June of 1940, suspended and total load sediment measurements were made along the North Fork of the Boise River near Twin Springs, Cottonwood Creek, and Grouse Creek (Seavy, 1948). However, these data were provided in lump sums for 6 months periods making it difficult to determine how much was brought in by one storm event. Based on the lump sum measurements for total sediment load, an average of 60 acre-ft was measured above Arrowrock Dam between January and June, and only 1.4 acre-ft was measured from July to December. The maximum inflow measured at Twin Springs during the January to June measurements was 5,020 cfs, and during the July to December measurements was 730 cfs.

Although the exact quantity of sediment transported through Arrowrock Reservoir during a storm event is difficult to estimate, the percentage that will be passed through to Lucky Peak Reservoir can be approximated using the trap efficiency results. Based on the sediment samples taken upstream of the dam, 62% of the sediment flushed will be .016mm or larger in grain size and the remaining 38% will be smaller than .016 mm. If the sluice gates are opened during a 5- or 10-year storm event when the reservoir is partially drawn down (elevation 3,027), 80-95 % of the volume of sediment transported to Arrowrock Dam could be passed through to Lucky Peak Reservoir. This sediment would be in addition to the volume scoured out upstream of the dam. Of the volume that could be flushed into Lucky Peak Reservoir if it is drawn down to elevation 2,962, 30-45% of the finer silts may be trapped depending on the how long the sluice gates are in operation. Approximately 70-75% of any flushed coarse silts will be trapped in Lucky Peak Reservoir.

CONCLUSIONS

This study addressed sedimentation release issues for Arrowrock and Lucky Peak Reservoir during the Arrowrock Dam valve replacement project for Alternative A. During Years 1 and 2 of the valve replacement project, very minimal existing sediment will be released out of Arrowrock Reservoir because the upper and middle outlets on Arrowrock Dam will be used to maintain reservoir elevations if a flood occurs, rather than the lower level sluice gates. The only existing sediment that may be passed through to Lucky Peak Reservoir is a small amount of suspended sediment mobilized during a storm event. This amount would be very small (unmeasurable) relative to sediment concentrations in the Boise River during a flood.

During Year 3 of the valve replacement project, Arrowrock Reservoir will be partially drawn down to allow for construction on the upstream face of Arrowrock Dam. Lucky Peak Reservoir will also be partially drawn down during Year 3 to allow the sluice gates on Arrowrock Dam to be opened to maintain reservoir level if a 5-year (4,300 cfs) or greater storm occurs. During the partial drawdowns, minor reworking of sediment along the reservoir bottoms will occur. Very minimal existing sediment will be released out of Arrowrock Reservoir during this period unless the sluice gates are opened. If the sluice gates are never opened during the valve replacement project, regardless of the lake elevation, the impact to existing Arrowrock Reservoir sediment is negligible.

If the sluice gates are opened during Year 3 to pass a flood, short-term, high sediment concentrations will be released from each gate causing a portion of the 20 feet of sediment deposited upstream of Arrowrock Dam to be flushed into Lucky Peak Reservoir. The sediment located along the reservoir bottom upstream of Arrowrock Dam was determined to be 75% silts, 20% clay, and 5% sand. The release of the silts and clays may initially result in a small scour cone upstream of each gate, but eventually this scour will be supply-limited due to only a partial drawdown of Arrowrock Reservoir. Based on the size of the sediment measured upstream of Arrowrock Dam and partially drawn down lake elevation during Year 3, it is estimated that each sluice gate will cause approximately 2 acre-feet of silt sized sediment to be flushed into Lucky Peak Reservoir if the sluice gates are opened to pass a 5- to 10-year storm. The discharge of sands along the reservoir margins will be transport-limited throughout the flushing event. If all five sluice gates are operated, a total of 8 to 10.5 acre-ft of silt sized sediment is estimated to be flushed out of Arrowrock Reservoir. In addition, it is estimated that 80-95 % of any sediment carried by a storm through Arrowrock Reservoir may also be passed through the sluice gates to Lucky Peak Reservoir.

If for any reason during the valve replacement the sluice gates remain open, resulting in a lowering of Arrowrock Reservoir to the elevation of the sluice gates, the hydraulic and flushing processes will be significantly different than if the gates are used only to maintain the partial drawdown level. A complete drawdown would result in riverine flow throughout the entire reservoir, and a much larger quantity of sediment flushed out in addition to a scoured channel along the reservoir. At a full drawdown of Arrowrock Reservoir to elevation 2,967, the sediment flushed into Lucky Peak Reservoir would increase by one to two orders of magnitude (an increase by a factor of 10 to possibly a factor of 100)

(Morris and Fan, 1998). The majority of sediment flushing would occur during the final drawdown stages. Volumes of sediment flushing, assuming all five sluice gates are operated during the entire drawdown, are estimated to reach 520 to 1250 acre-ft. These estimates depend on the upper extent of channel scouring.

Because Arrowrock and Lucky Peak Reservoirs are located in series, if the sluice gates are used to pass a flood during Year 3, a portion of the sediments released will accumulate in Lucky Peak Reservoir. As documented in a video of the 1987 flushing, a portion of the sediment will deposit just downstream of Arrowrock Dam. However, Arrowrock Reservoir was completely drawn down in 1987 to the elevation of the sluice gates causing a much larger volume of sediment to be flushed than estimated for Year 3 of the valve replacement project. Assuming Arrowrock Reservoir will not be drawn down to the elevation of the sluice gates, the sediment volume flushed would me much smaller. The majority of flushed sediment would be transported through the upper 6-7 miles of riverine type flow in Lucky Peak Reservoir, and deposited downstream where the water surface becomes level.

During the construction period from September 1 to October 31 when Lucky Peak Reservoir would be held at lake elevation 3,000, it is estimated that approximately **b** of the sediment flushed from Arrowrock Reservoir (whatever the volume) would be trapped in Lucky Peak Reservoir. When Lucky Peak is drawn down to lake elevation 2,962 during November 1 to February28, approximately ½ of the sediment flushed is estimated to become trapped in Lucky Peak Reservoir. The remaining flushed sediment has the potential to be released from Lucky Peak Reservoir downstream to the Boise River. The amount of sediment flushed from Lucky Peak Reservoir depends on the magnitude and duration of the storm events (and subsequent release from Arrowrock Reservoir), and the outlet works operation at Lucky Peak Dam. In general, these trap efficiency estimates may be low. When Lucky Peak is drawn down in Year 3 to elevation 2,962, the water travel time during a 5- to 10-year storm event is approximately 7 to 10 days. It is unlikely that the sluice gates on Arrowrock Dam would be opened long enough for the majority of flushed sediment to reach Lucky Peak Dam (unless the sluice gates were operated for longer than a 1 week period). A more likely scenario is the sediment will gradually be reworked throughout Lucky Peak Reservoir, and eventually reach the dam over time.

Sediment flushing events are very unstable and difficult to measure due to the rapidly changing channel geometry, inflow, lake elevation, and outlet configurations. However, it would be beneficial to collect some data for future reference if the sluice gates are operated for a long enough duration during the valve replacement project. Possible data collection could involve monitoring Arrowrock and Lucky Peak Reservoirs for evidence of a density current through temperature, dissolved oxygen, or suspended sediment measurements, recording duration of sluice gate operation and lake elevation, and visual observations of flushing. Possibly the most beneficial piece of information would be to survey Arrowrock and Lucky Peak Reservoirs prior to the proposed valve replacement and just after a possible flushing event. This would verify the volume of sediment flushed out of Arrowrock Reservoir, and the volume trapped in Lucky Peak Reservoir.

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